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RESEARCH MEMORANDUM

LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS OF 1.41 AND 2.01 OF A 67° SWEPT-WING AIRPLANE CONFIGURATION WITH CANARD CONTROL SURFACES

By M. Leroy Spearman and Ross B. Robinson

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Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON
July 7, 1958
Declassified January 12, 1961

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LONGITUDINAL STABILITY AND CONTROL CHARACTERISTICS AT MACH NUMBERS OF 1.41 AND 2.01 OF A 67° SWEPT-WING AIRPLANE CONFIGURATION WITH CANARD CONTROL SURFACES*

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SUMMARY

An investigation has been conducted in the Langley 4- by 4-foot supersonic pressure tunnel at Mach numbers of 1.41 and 2.01 to determine the stability and control characteristics of a canard-controlled airplane configuration having potentially high values of lift-drag ratio. The configurations investigated included both a plane and a twisted wing with approximately 67° of sweep and an aspect ratio of 2.91 and three trapezoidal canard surfaces having ratios of exposed area to wing area of 0.032, 0.076, and 0.121.

Each of the configurations investigated indicated a tendency toward longitudinal instability at high lifts that might limit the maximum trimmed lift-drag ratios L/D to values less than those potentially available. For example, the maximum trimmed value of lift-drag ratio obtainable without high-lift instability was 8.2 for a low-lift static margin of 20 percent at a Mach number of 1.41 for the configuration with the twisted wing and smallest control. This value compares with the maximum trimmed value of 9.15 obtained for a low-lift static margin of 11 percent but instability occurs for lift coefficients just above that for maximum lift-drag ratio.

For low stability levels the maximum values of trimmed L/D were highest with the small canard, whereas for high stability levels the values of trimmed L/D were higher with the large canards.

INTRODUCTION

Recent investigations conducted in the Langley 4- by 4-foot supersonic pressure tunnel at Mach numbers of 1.41 and 2.01 have indicated

*Title, Unclassified.

relatively high values of maximum lift-drag ratio for a wing-body configuration having a highly swept wing. Inasmuch as the attainment of high lift-drag ratios is essential for obtaining maximum range benefits for supersonic aircraft, the investigation has been extended to determine the extent to which the lift-drag ratios obtained for the wing-body combination would be affected by the addition of stabilizing and controlling surfaces. A canard pitch control was selected since the results of other investigations (ref. 1, for example) have indicated that canard controls may reduce the losses in lift-drag ratio due to trimming.

The configurations investigated included a plane wing and a twisted wing having highly swept plan forms. Three different canard surfaces having trapezoidal plan forms were investigated and a single swept body-mounted vertical tail was employed.

SYMBOLS

The results are presented as force and moment coefficients referred to the stability axis system with the moment reference point at body station 21.97.

C_L lift coefficient, $\frac{\text{Lift}}{qS_W}$

C_D drag coefficient, $\frac{\text{Drag}}{qS_W}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS_W\bar{c}_W}$

S_W wing area including body intercept

S_c exposed area of canard surface

$\bar{c}_W$ wing mean geometric chord

c local chord

q free-stream dynamic pressure

l distance from canard midchord point to moment reference point

M	Mach number
L/D	lift-drag ratio, C_L/C_D
$\left(\partial C_m/\partial C_L\right)_o$	longitudinal stability parameter measured at C_L and $\delta_c = 0$
α	angle of attack, deg
δ_c	canard deflection, positive when trailing edge is down, deg
$\frac{S_c l}{S_w \bar{c}_w}$	canard volume coefficient
C_{m_δ}	canard pitch effectiveness

Subscripts:

c	canard
w	wing
o	zero lift
max	maximum value
trim	value at $C_m = 0$

Components:

B	body
W	wing
V	vertical tail
C	canard surface

MODEL AND APPARATUS

Details of the model are shown in figure 1 and the geometric characteristics are given in table I. A photograph of the model is shown in figure 2. Coordinates for the area-rule-type body are given in table II. The model was tested with plane and twisted wings that were composed of NACA 65A series sections with thickness ratios of 4 percent at the root and 3 percent at the tip. The wings had sweep angles of about 67° and aspect ratios of 2.91. The twisted wing employed a linear twist to 4° washout at the tip. The vertical-tail and canard surfaces had hexagonal sections and had a thickness ratio of 3 percent. Three sizes of canard surfaces were tested; these were designated as small, medium, and large and had ratios of exposed area to wing area of 0.032, 0.076, and 0.121, respectively. The force and moment data were obtained through the use of a six-component internal strain-gage balance.

TESTS, CORRECTIONS, AND ACCURACY

The tests were made at Mach numbers of 1.41 and 2.01 with a stagnation pressure of 10 pounds per square inch and a stagnation temperature of 100° F. The dewpoint was maintained sufficiently low (below -25° F) so that no condensation effects were encountered in the test section. The angle of attack was corrected for the deflection of the balance and sting under load. The base pressure was measured and the drag was adjusted to a base pressure equal to free-stream static pressure.

The estimated accuracy of the individual measured quantities based on repeatability and zero shifts is as follows:

C_L	±0.0017
C_D	±0.0003
C_m	±0.0003
α, deg	±0.1
δ_c, deg	±0.1

The tests were made through an angle-of-attack range from about -4° to about 17° at zero sideslip. The twisted wing was tested with the small, medium, and large canard surfaces only at a Mach number of 1.41. The plane wing with the medium canard surface was tested at Mach numbers of 1.41 and 2.01.

DISCUSSION

Effects of Components

The aerodynamic characteristics in pitch at $M = 1.41$ for the twisted-wing configuration are presented in figure 3 for various combinations of component parts and in figure 4 for various canard surface sizes.

The maximum lift-drag ratio obtained for the basic wing-body combination is about 10.2. (See fig. 3(d).) The addition of the vertical tail causes a slight increase in minimum drag and a decrease in maximum L/D. (See fig. 3(d).) The addition of canard surfaces causes further increases in minimum drag and the values of maximum L/D become progressively lower as the canard size is increased (fig. 4(b)); thus, for the complete configurations the maximum values of L/D are about 9.2 with the small canard and about 8.1 with the large canard.

The pitching-moment results indicate a tendency toward reduced stability at high lifts or high angles of attack even for the wing-body configuration. (See figs. 3(a) and 3(c).) This tendency toward reduced stability with increasing lift could result in a pitch-up condition for lower static margins. The addition of canard surfaces results in a further decrease in longitudinal stability and consequently the pitch-up tendency becomes progressively worse as the canard size increases. (See fig. 4(a).)

The effects of component parts for the plane-wing configuration at $M = 1.41$ (fig. 5) are similar to those for the twisted wing but indicate that the maximum values of L/D are slightly lower for the plane wing than for the twisted wing primarily because of the higher drag due to lift for the plane wing.

The effects of component parts for the plane-wing configuration at $M = 2.01$ (fig. 6) are similar to those for $M = 1.41$ except that the maximum values of L/D are reduced primarily because of the decrease in lift-curve slope and the increase in drag due to lift with increasing Mach number.

Effects of Control Deflection and Trimming

The effects of control deflection on the aerodynamic characteristics in pitch for the twisted-wing configuration at $M = 1.41$ are presented in figures 7, 8, and 9 for the small, medium, and large canard surfaces, respectively. The effects of control deflection for the configuration with the plane wing and medium canard surface are shown in figure 10 for $M = 1.41$ and in figure 11 for $M = 2.01$.

Since these results are for a constant center-of-gravity position (body station 21.97), it is obvious that the level of stability as well as the control effectiveness would change as the canard size changes. The variation of control pitch effectiveness C_{m_δ} and static longitudinal stability $\left(\partial C_m/\partial C_L\right)_0$ with canard volume coefficient $\frac{S_c l}{S_w \bar{c}_w}$ is shown in figure 12 for the configuration with the twisted wing at $M = 1.41$. The estimated variations were obtained by the method of reference 2 and do not include interference effects between the canard surfaces and the wing. The experimentally determined variations of C_{m_δ} and $\left(\partial C_m/\partial C_L\right)_0$ with canard volume coefficient are in reasonably good agreement with the estimated variations except for the higher canard volume coefficients where the experimental values indicate a greater increase in C_{m_δ} and a greater decrease in $\left(\partial C_m/\partial C_L\right)_0$ than estimated. This may be the result of an interference effect of the canard-surface flow field on the wing wherein the increase in canard size causes an increase in downwash at the wing such that the wing lift and wing contribution to pitching moment are reduced.

The maximum trim values of L/D as a function of static stability near zero lift $\left(\partial C_m/\partial C_L\right)_0$ are shown in figure 13 for each of the complete configurations investigated. These values were obtained from the data presented in figures 7 to 11 for various arbitrary stability levels. For stability levels where the values of maximum L/D occurred for control deflections other than those tested, the values were obtained by assuming a linear variation of pitching moment and lift-drag ratio with canard deflection.

As would be expected, the values of maximum trimmed L/D decrease as the stability level is increased for all configurations. The effect of increasing the canard surface size for the twisted-wing configuration at $M = 1.41$ (fig. 13(a)) is to decrease the rate at which the maximum trimmed L/D changes with stability level. However, there is a considerable decrease in L/D with increasing canard size for the zero stability level, L/D varying from about 10.2 for the small canard to about 8.7 for the large canard. However, for each configuration, a stability level $\left(\partial C_m/\partial C_L\right)_0 \approx -0.20$ is required to avoid instability at high lifts, and for this condition the maximum trimmed L/D is about 8 regardless of the canard size. For higher stability levels the maximum trimmed L/D generally becomes higher as the canard size is increased.

Wing twist had little effect on the variation of maximum L/D with stability level for the configuration with the medium canard (fig. 13(b)) but, because C_{m_0} is positive, did provide an increment in maximum trimmed L/D of about 1. Increasing the Mach number to 2.01 for the plane-wing configuration results in a further decrease in the maximum values of L/D throughout the stability range.

Although the values of L/D indicated for these configurations are relatively high, the fact is nonetheless disconcerting that none of the configurations could be trimmed to their highest potential L/D without the occurrence of instability at high lifts. For example, the configuration with the twisted wing and small canard at $M = 1.41$ (fig. 7) could be trimmed to its maximum L/D of 9.15 with $\delta_c = 0^\circ$, and a static margin near zero lift of 11 percent $\bar{c}$, but instability occurs at lift coefficients just beyond that for maximum L/D. This value would be a significant increase in L/D above the value of 8.2 obtained for a low-lift static margin of about 20 percent $\bar{c}$ that is required in order to avoid instability at high lifts. (See figs. 7 and 13.) Hence, every effort should be made to find means to linearize the moment variations for configurations of this type in such a way that the maximum L/D potential might be realized.

CONCLUDING REMARKS

An investigation has been conducted in the Langley 4- by 4-foot supersonic pressure tunnel at Mach numbers of 1.41 and 2.01 to determine the stability and control characteristics of various canard-controlled airplane configurations having a potentially high value of lift-drag ratio. The configurations investigated included both a plane and a twisted wing with approximately 67° sweep and aspect ratios of 2.91 and three trapezoidal canard surfaces having ratios of exposed area to wing area of 0.032, 0.076, and 0.121.

The results of the investigation indicated that none of the configurations could be trimmed to their best lift-drag ratio without the occurrence of longitudinal instability at high lifts. For example, the configuration with the twisted wing and small canard at $M = 1.41$ could be trimmed to a maximum lift-drag ratio L/D of 9.15 with a static margin at low lifts of 11 percent but instability occurs at lift coefficients just beyond that for maximum L/D. The maximum value of L/D obtainable without instability occurring at high lifts was about 8.2 at a low-lift static margin of about 20 percent.

For low stability levels the maximum values of trimmed L/D were highest with the small canard, whereas for high stability levels the values of trimmed L/D were higher with the larger canards.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 29, 1958.

REFERENCES

1. Spearman, M. Leroy: Some Factors Affecting the Static Longitudinal and Directional Stability Characteristics of Supersonic Aircraft Configurations. NACA RM L57E24a, 1957.

2. Pitts, William C., Nielsen, Jack N., and Kaattari, George E.: Lift and Center of Pressure of Wing-Body-Tail Combinations at Subsonic, Transonic, and Supersonic Speeds. NACA Rep. 1307, 1957.

TABLE I.- GEOMETRIC CHARACTERISTICS OF AIRPLANE CONFIGURATION

Wing:	
Total area, sq in.	198.00
Span, in.	24.00
Mean geometric chord, in.	10.73
Taper ratio, inboard	0.333
Taper ratio, outboard	0.500
Leading-edge sweep, inboard, deg	67.0
Leading-edge sweep, outboard, deg	61.7
Airfoil section	NACA 65A series
Thickness ratio, root, percent chord	4.0
Thickness ratio, tip, percent chord	3.0
Aspect ratio	2.91
Body:	
Length, in.	39.00
Maximum cross-sectional area, sq in.	6.072
Diameter of equivalent circle, in.	2.78
Length-diameter ratio	14.03
Base area, sq in.	2.99
Vertical tail:	
Area to body center line, sq in.	40.15
Tip chord, in.	3.16
Root chord, in.	10.82
Taper ratio	0.29
Span, in.	5.74
Aspect ratio, panel	0.82
Leading-edge sweep, deg	65.0
Airfoil section	Hexagonal
Thickness ratio, percent chord	3.0

Canard surface:

	Small	Medium	Large
Area, exposed, sq in.	6.32	14.96	23.92
Span, total, in.	4.64	6.58	8.00
Tip chord, in.	1.36	1.88	2.28
Root chord at center line, in.	3.39	4.69	5.71
Taper ratio	0.41	0.41	0.41
Leading-edge sweep, deg	23.2	23.2	23.2
Midchord sweep, deg	0	0	0
Ratio of exposed area to wing area	0.032	0.076	0.121

TABLE II.- BODY COORDINATES

Body station, in.	Radius, in.		Body station, in.	Radius, in.	
	Major axis	Minor axis		Major axis	Minor axis
0	0	0	21	1.325	1.195
1	.297	.198	22	1.257	1.195
2	.492	.328	23	1.198	1.195
3	.655	.437	24	1.211	1.195
4	.799	.533	25	1.260	1.195
5	.928	.619	26	1.332	1.195
6	1.045	.696	27	1.446	1.195
7	1.151	.767	28	1.514	1.195
8	1.248	.832	29	1.542	1.195
9	1.337	.891	30	1.554	1.195
10	1.418	.945	31	1.534	1.195
11	1.492	.995	32	1.489	1.195
12	1.559	1.040	33	1.433	1.195
13	1.620	1.080	34	1.369	1.182
14	1.666	1.116	35	1.303	1.155
15	1.666	1.149	36	1.231	1.117
16	1.645	1.175	37	1.155	1.072
17	1.609	1.190	38	1.067	1.025
18	1.551	1.195	39	.975	.975
19	1.482	1.195			
20	1.399	1.195			

Canard dimensions

	Small	Medium	Large
Span	4.64	6.58	7.99
Root chord (℄)	3.33	4.64	5.69
Tip chord	1.37	1.90	2.31

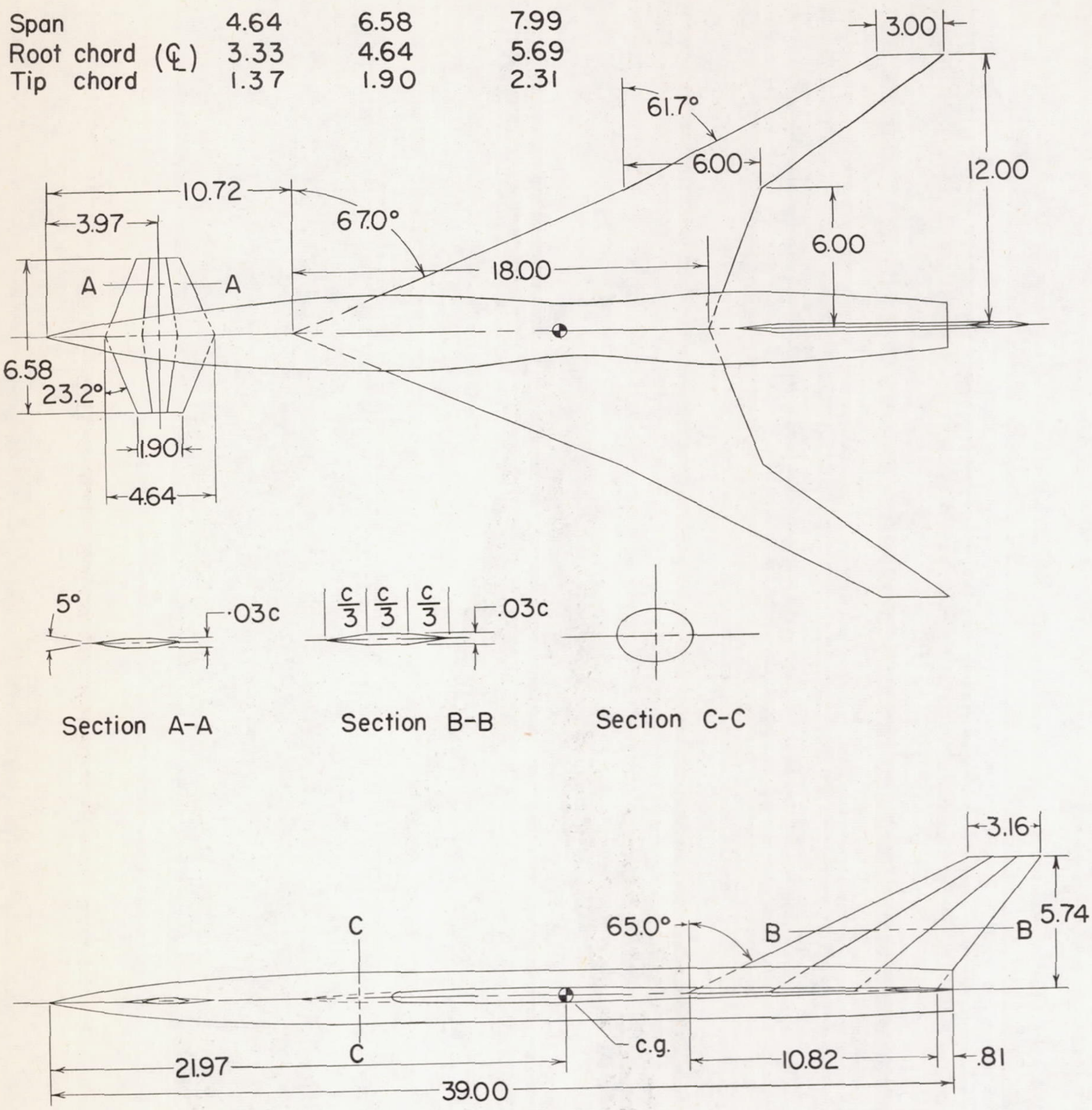

Figure 1.- Details of model with plane wing and medium canard. All linear dimensions are in inches.

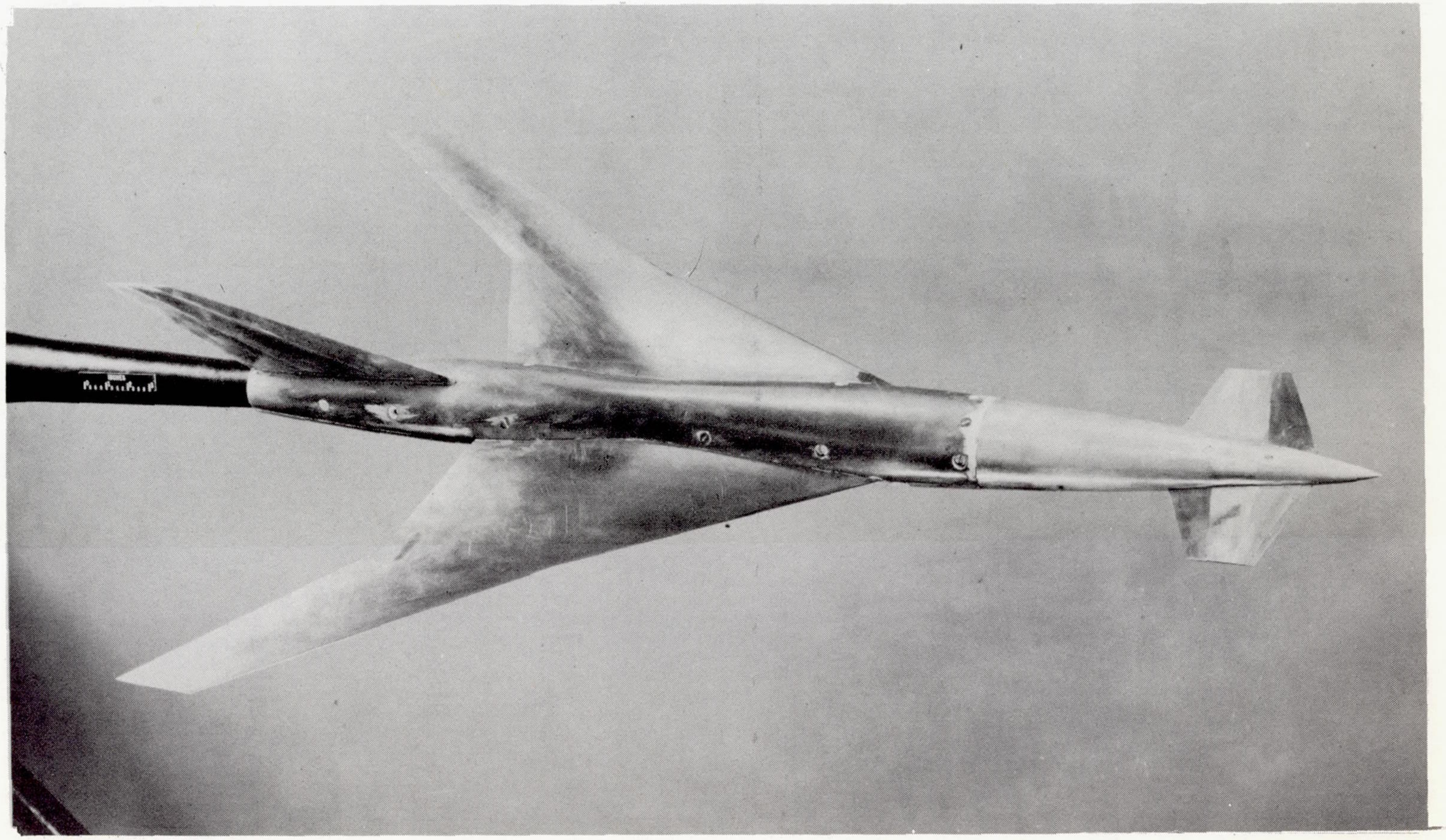

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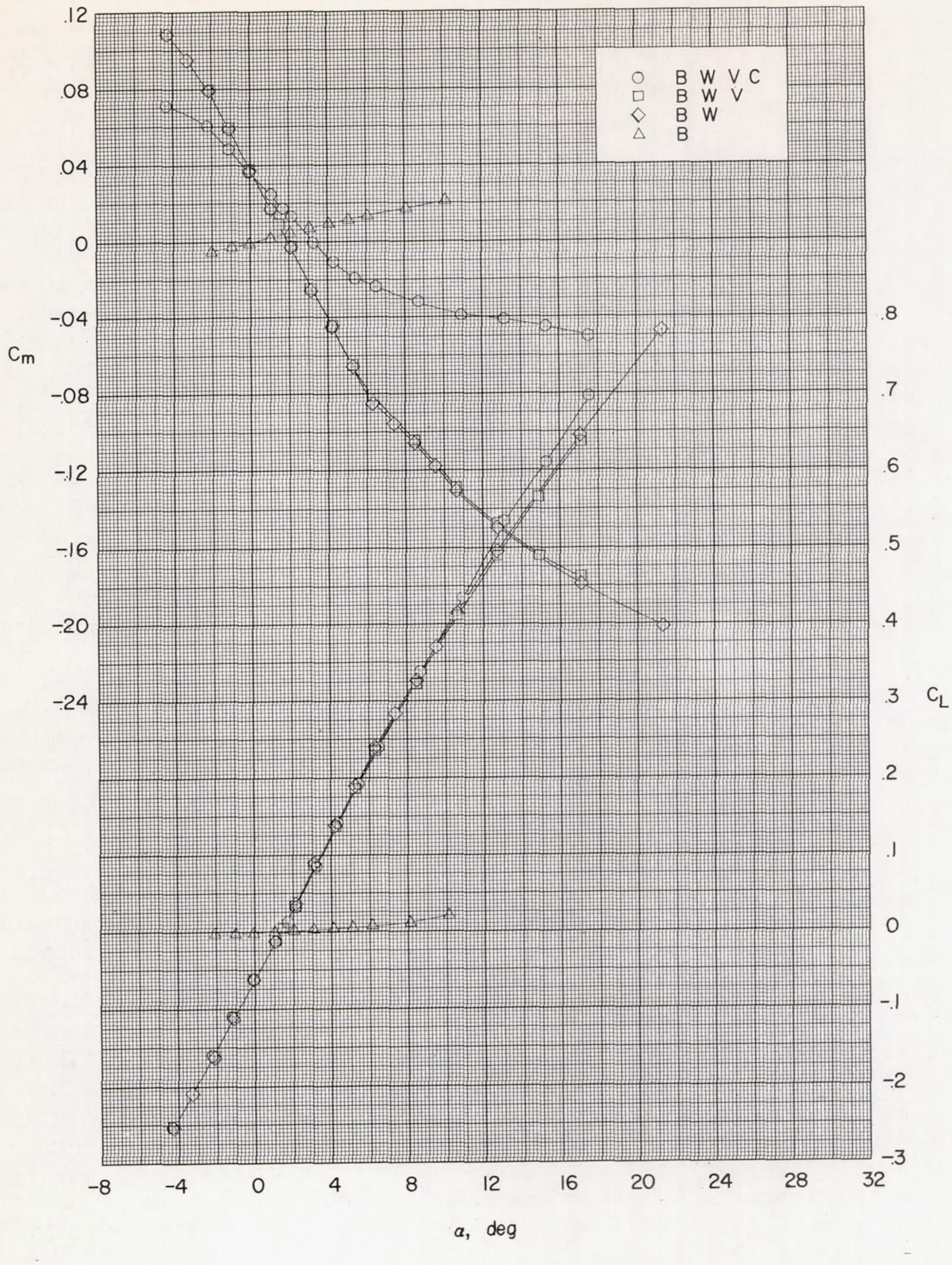
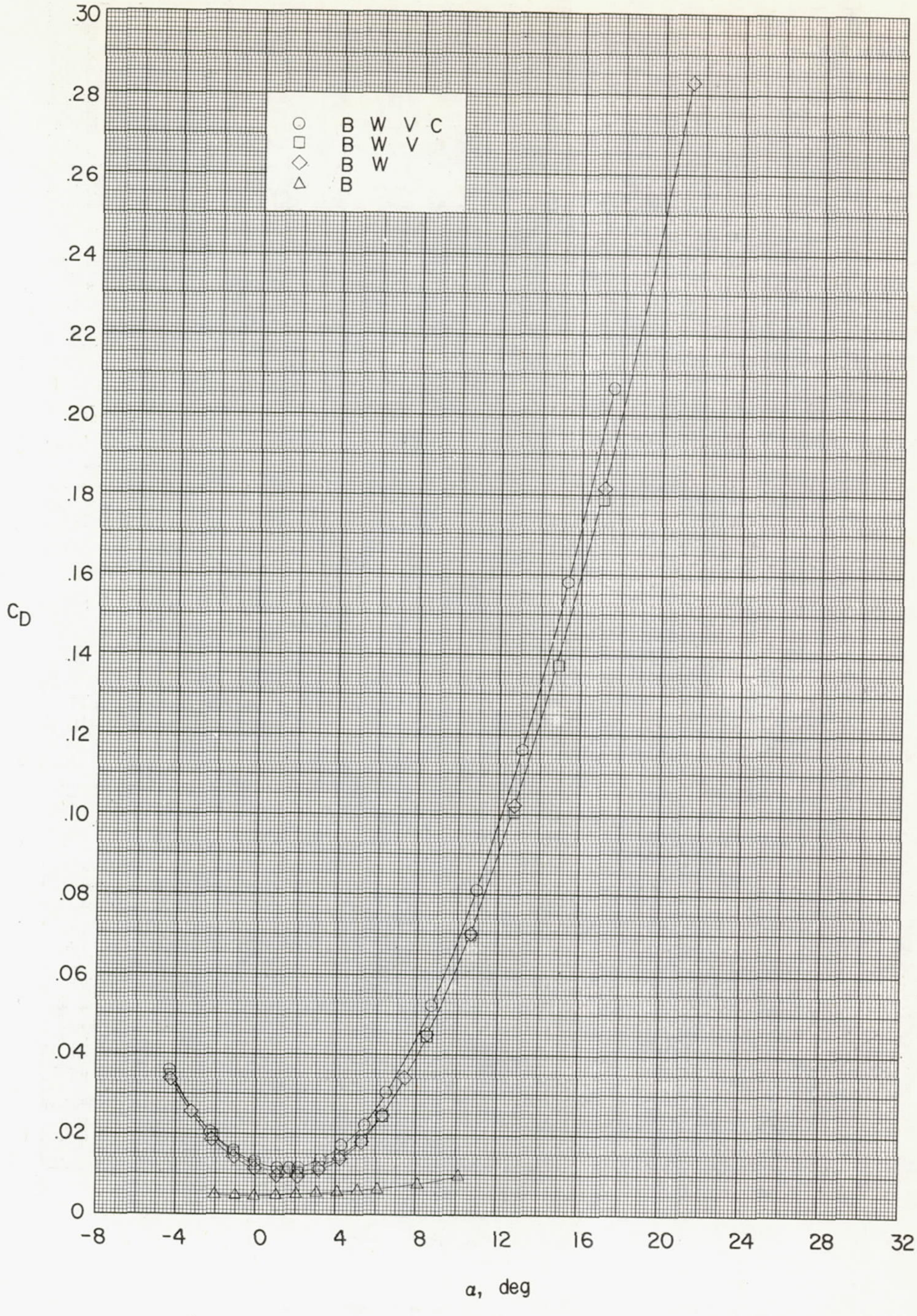
Figure 2.- Photograph of model with medium canard.



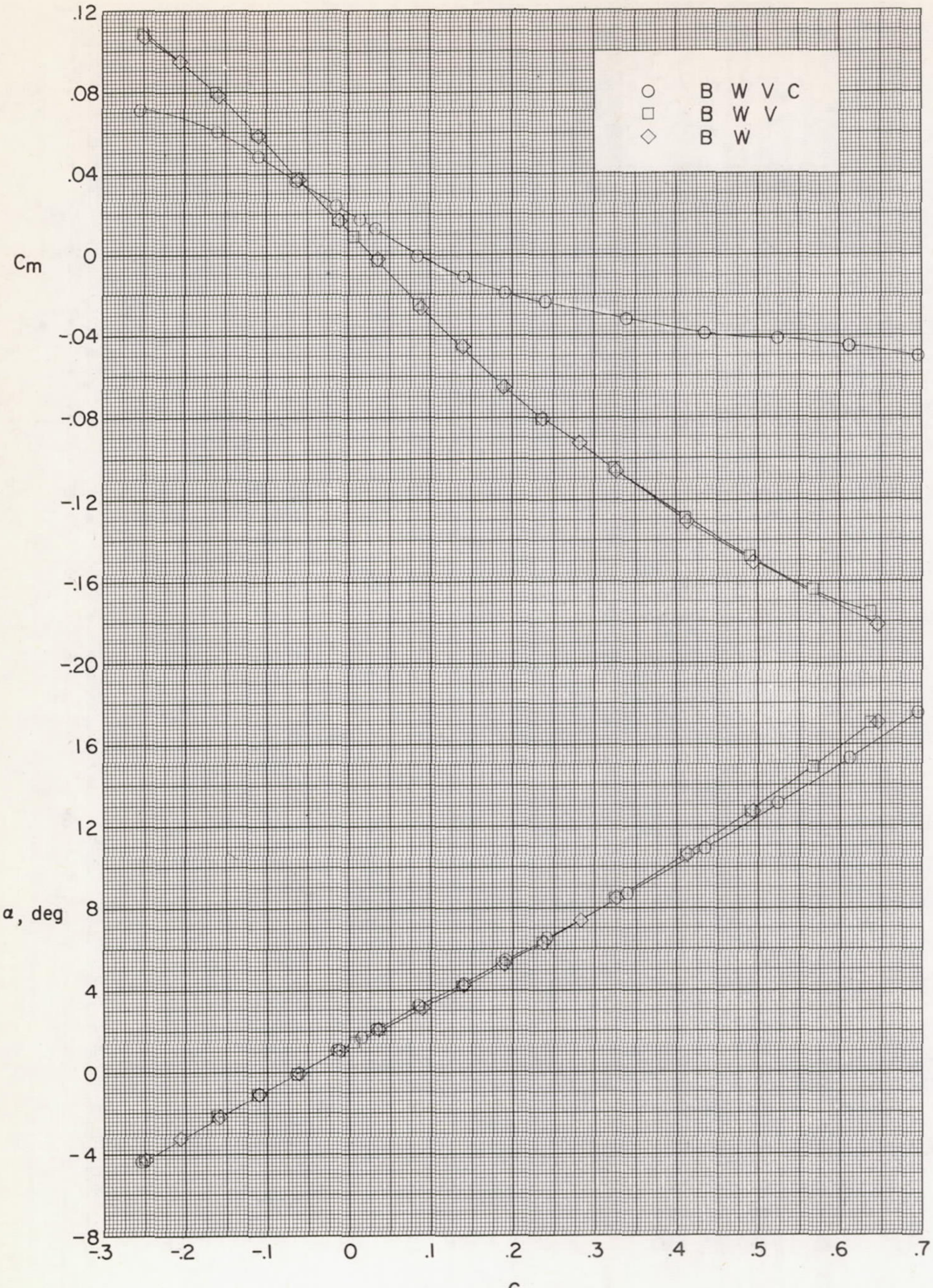
(a) Variation of C_m and C_L with α.

Figure 3.- Aerodynamic characteristics in pitch for various combinations of component parts. Twisted wing; medium canard; $M = 1.41$; $\delta_c = 0^{\circ}$.



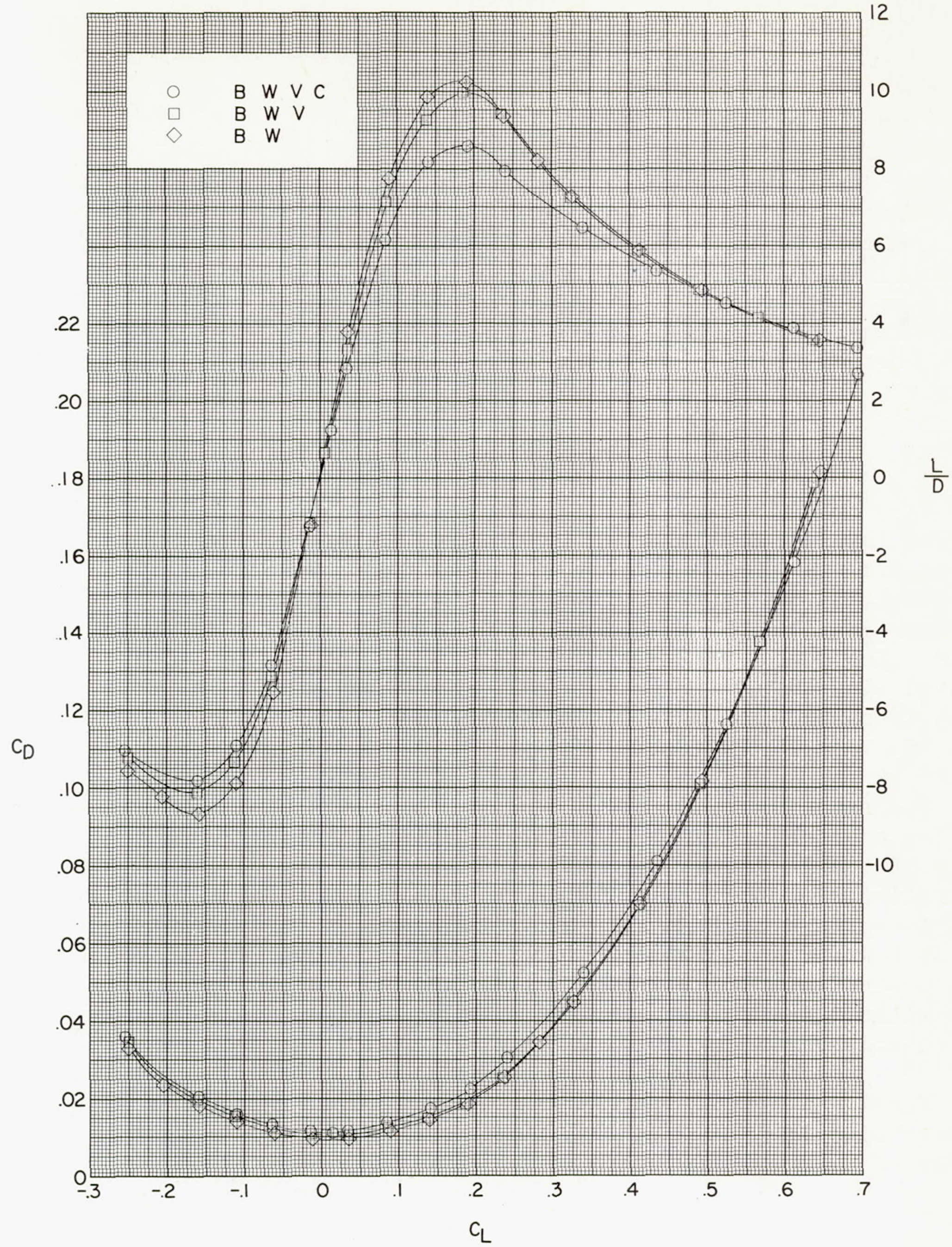
(b) Variation of C_D with α.

Figure 3.- Continued.



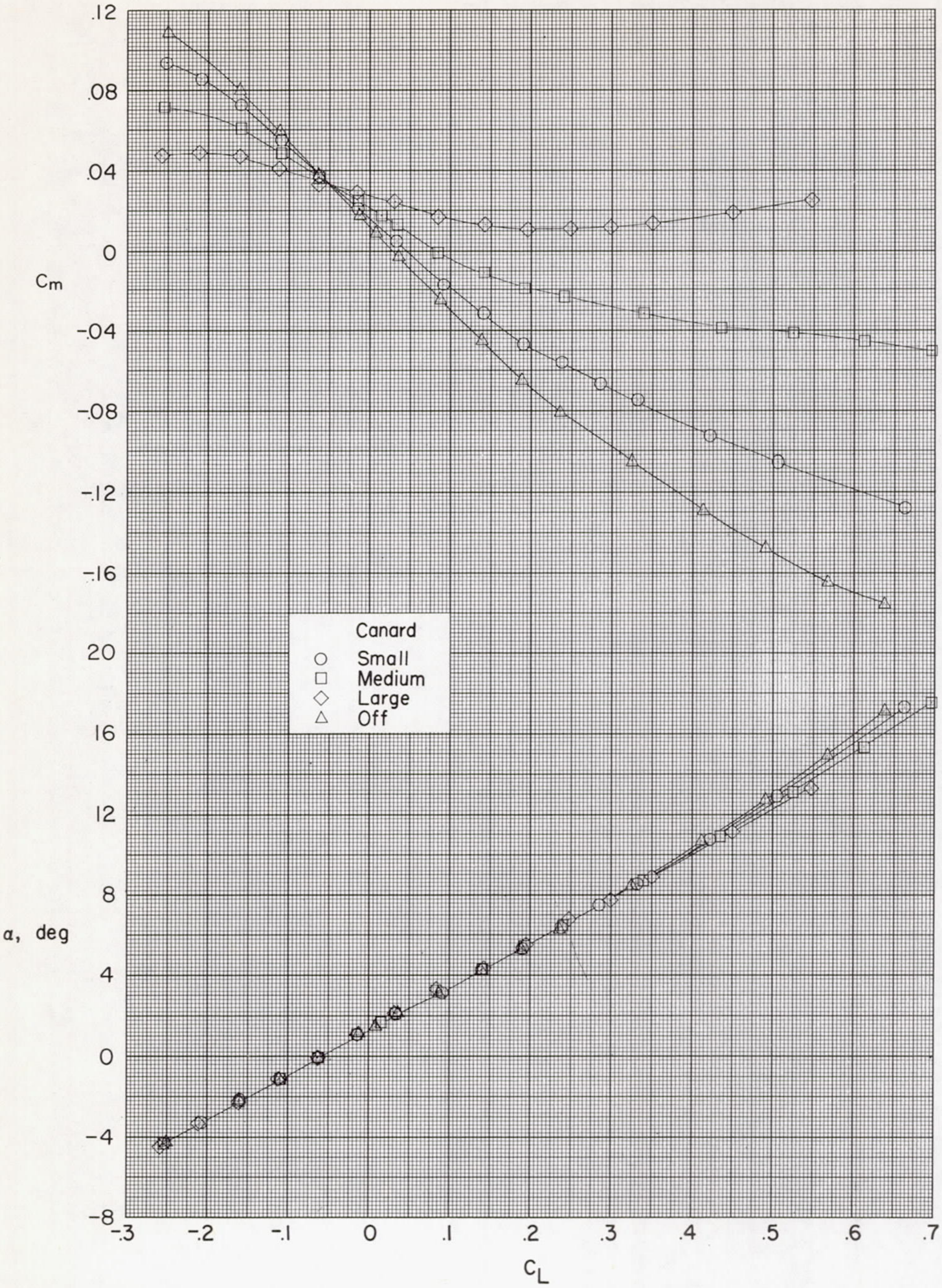
(c) Variation of C_m and α with C_L.

Figure 3.- Continued.



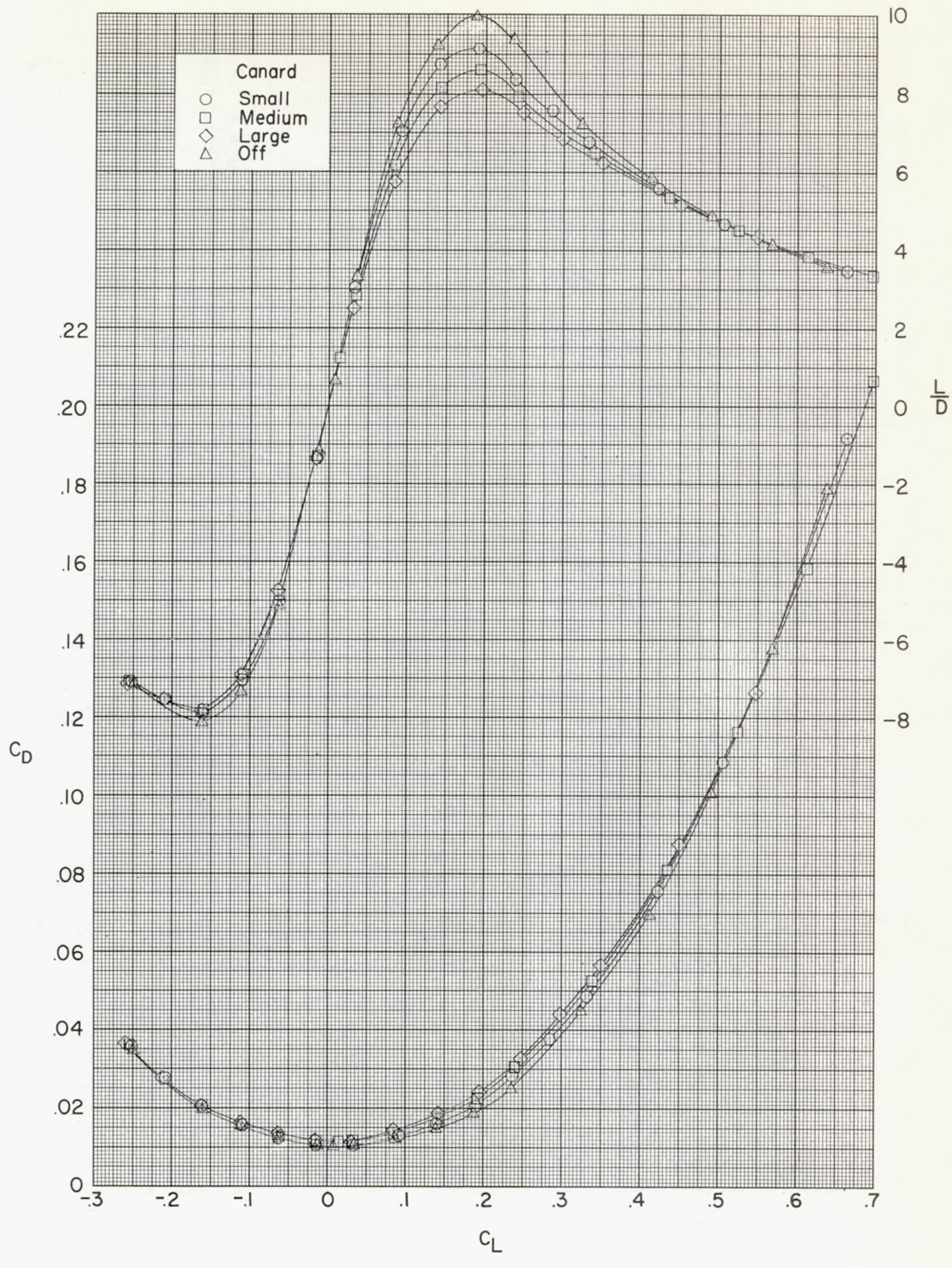
(d) Variation of C_D and L/D with C_L.

Figure 3.- Concluded.



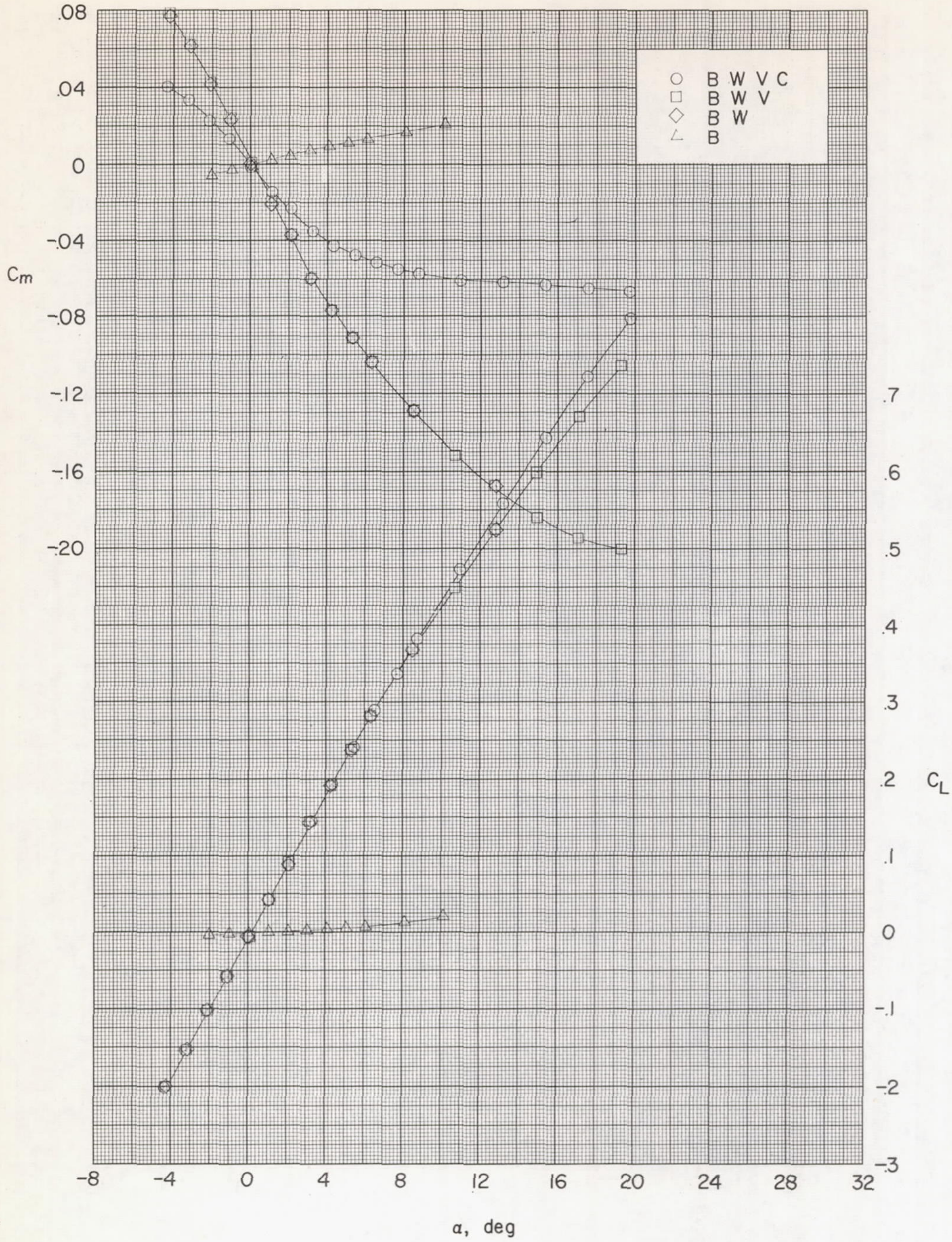
(a) Variation of C_m and α with C_L.

Figure 4.- Effect of canard size on aerodynamic characteristics in pitch. Twisted wing; vertical tail on; M = 1.41; δ_c = 0°.



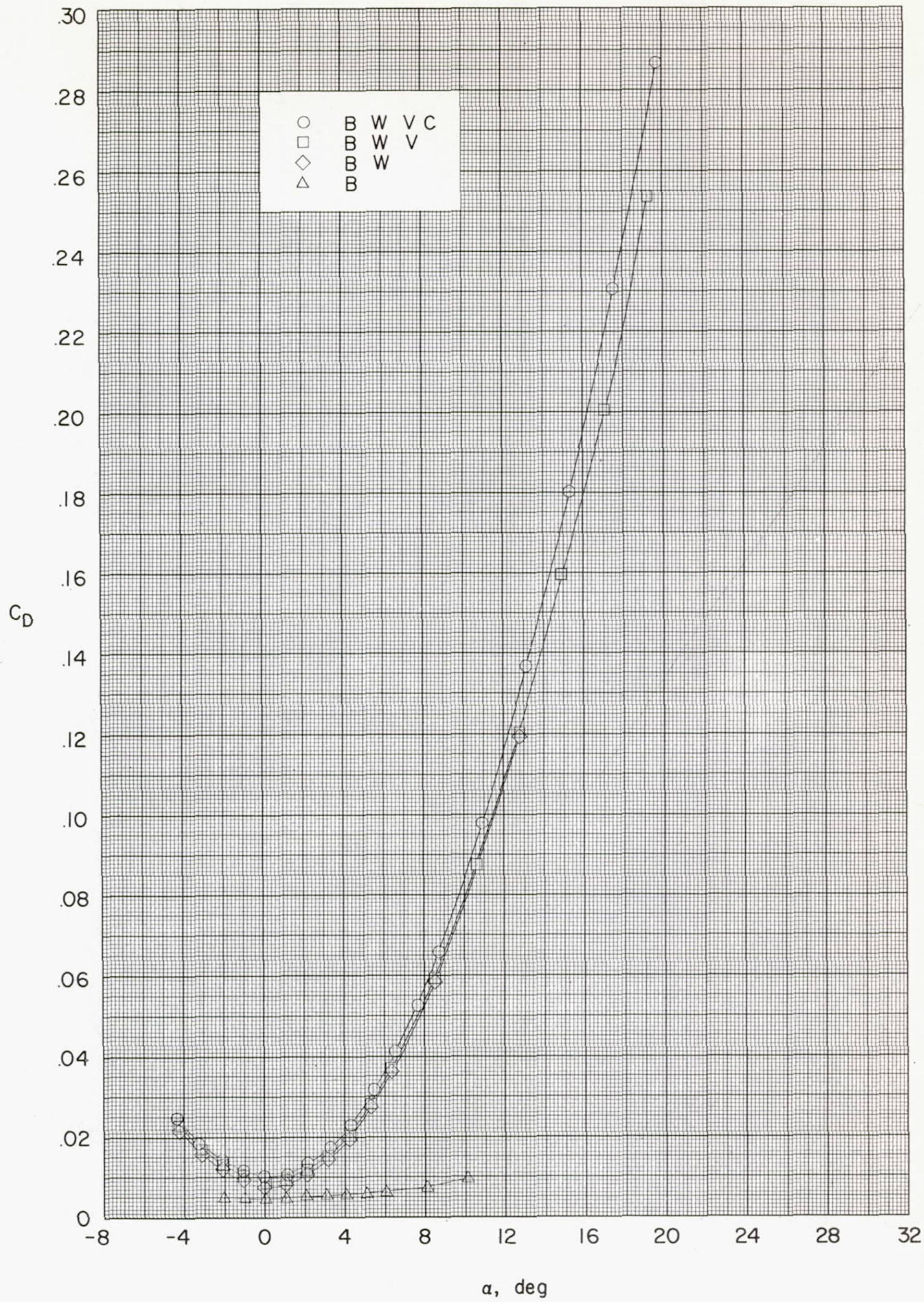
(b) Variation of L/D and C_D with C_L.

Figure 4.- Concluded.



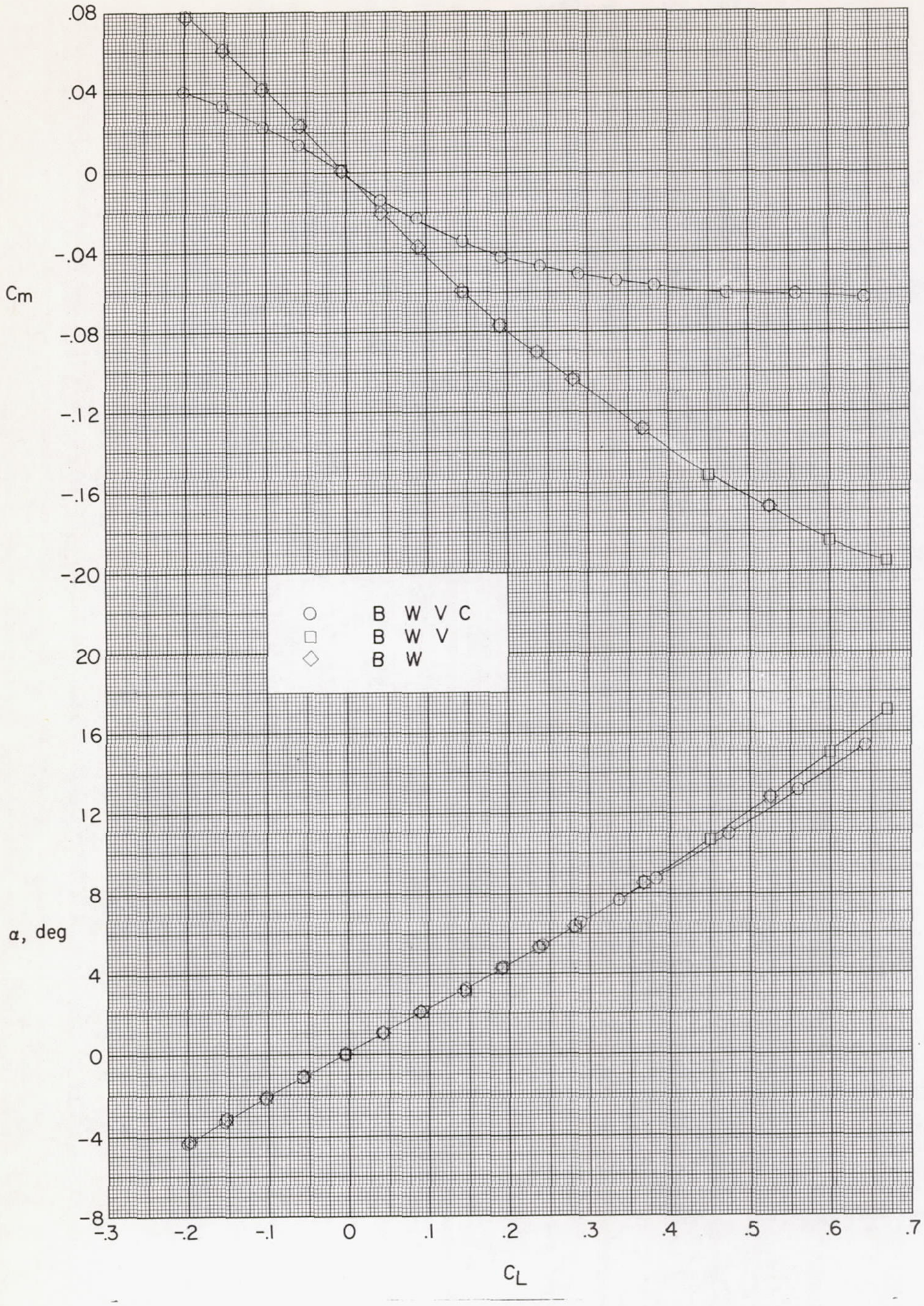
(a) Variation of C_m and C_L with α.

Figure 5.- Aerodynamic characteristics in pitch for various combinations of component parts. Plane wing; medium canard; $M = 1.41$; $\delta_c = 0^{\circ}$.



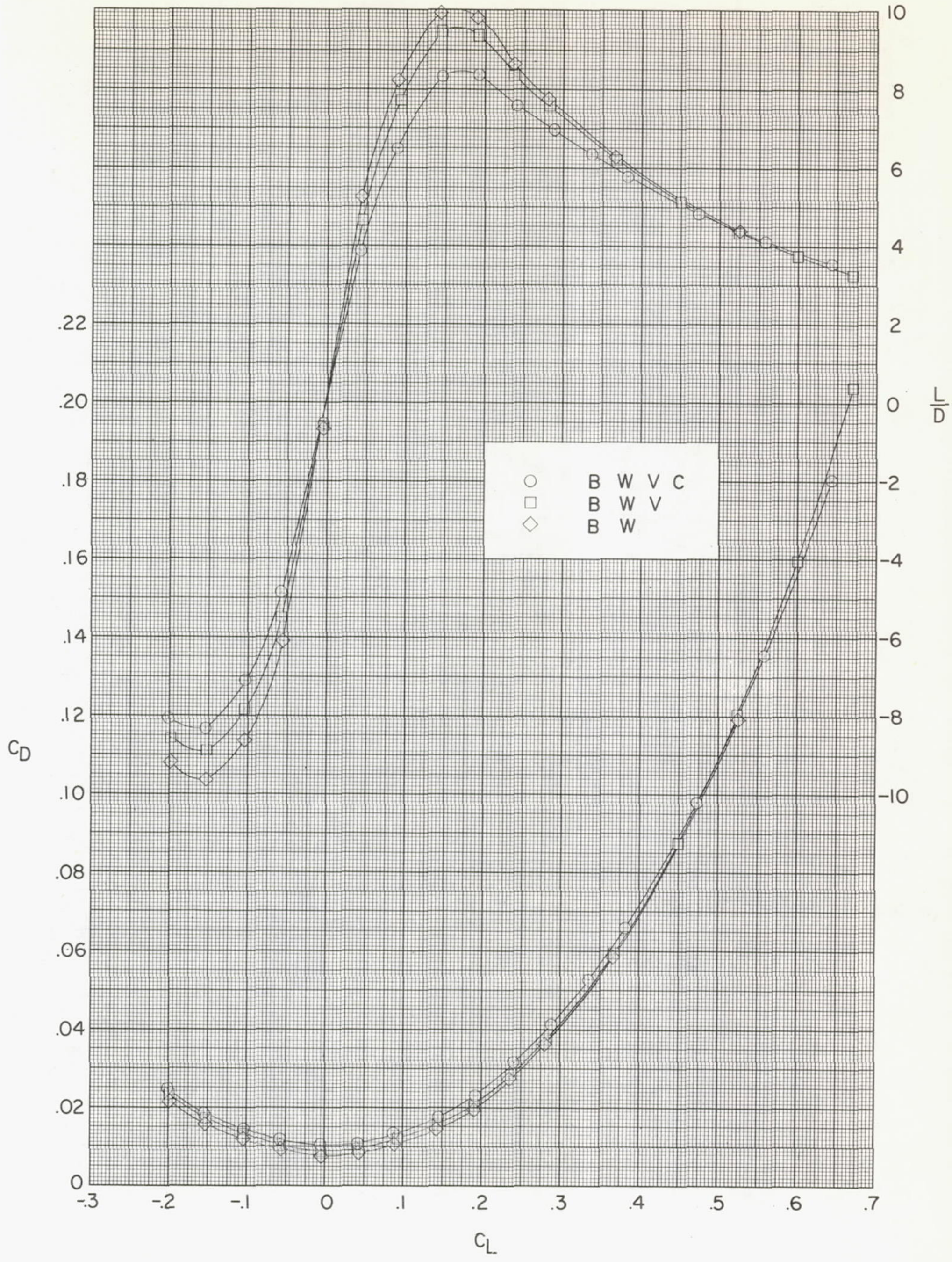
(b) Variation of C_D with α.

Figure 5.- Continued.



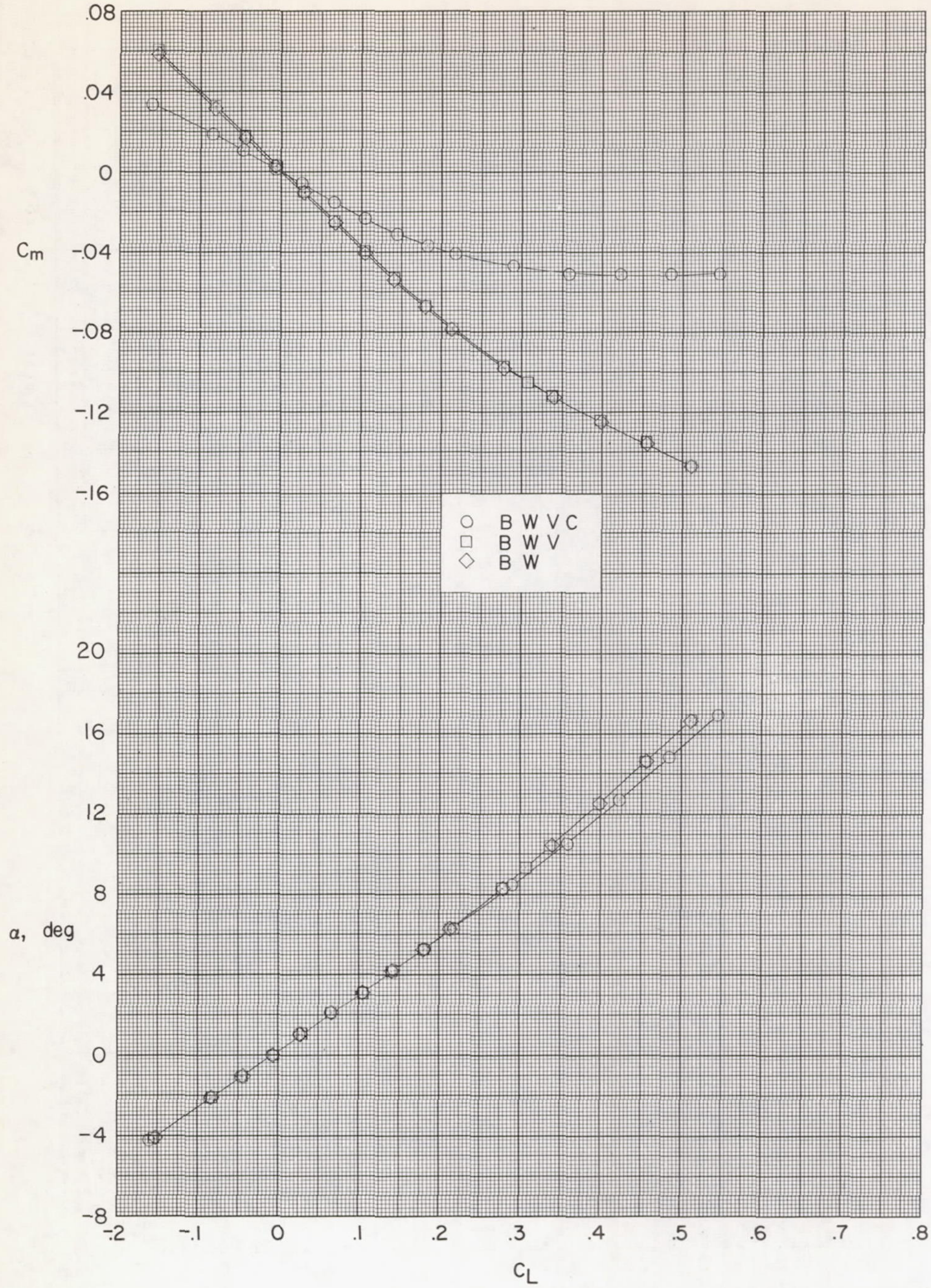
(c) Variation of C_m and α with C_L.

Figure 5.- Continued.



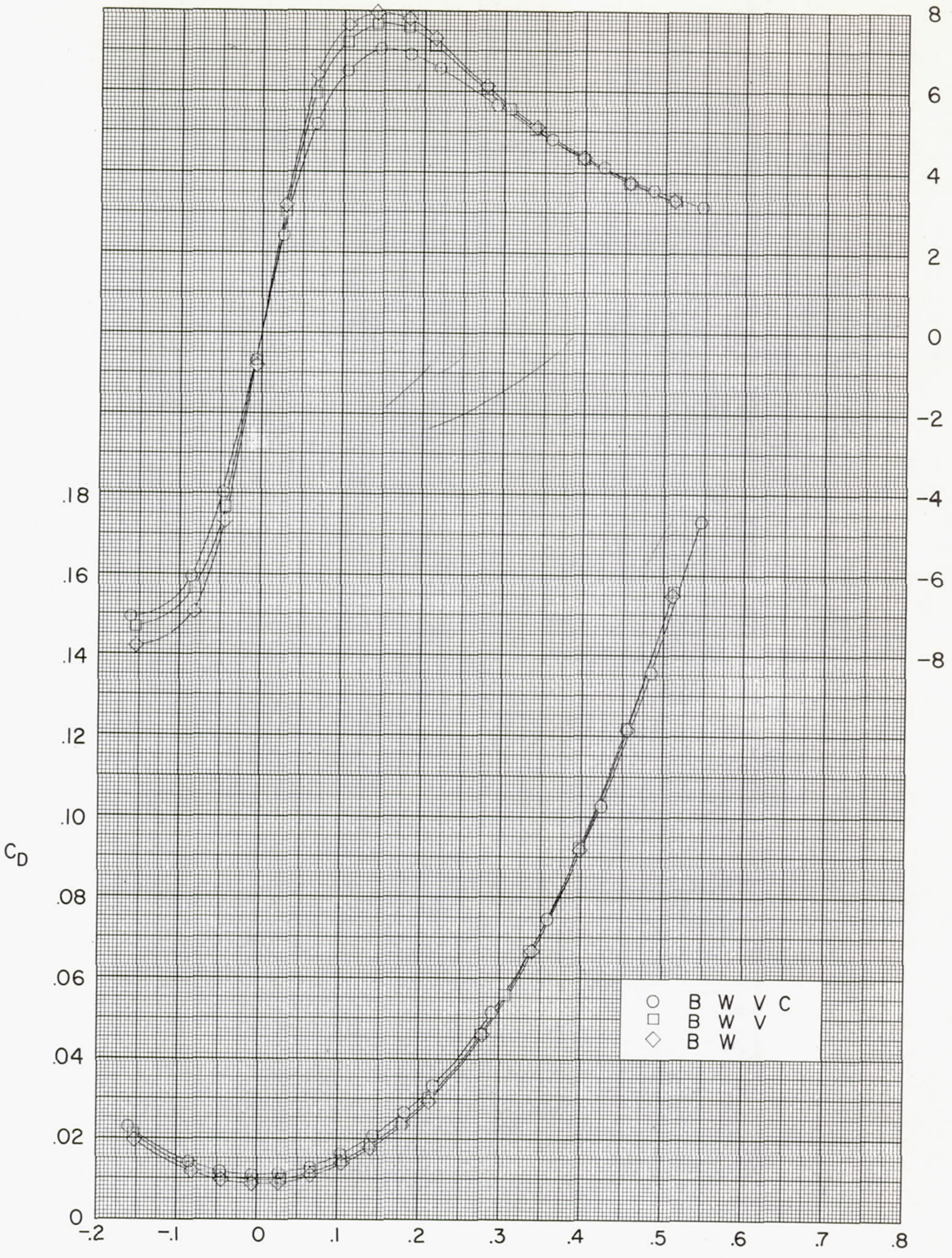
(d) Variation of C_D and L/D with C_L.

Figure 5.- Concluded.



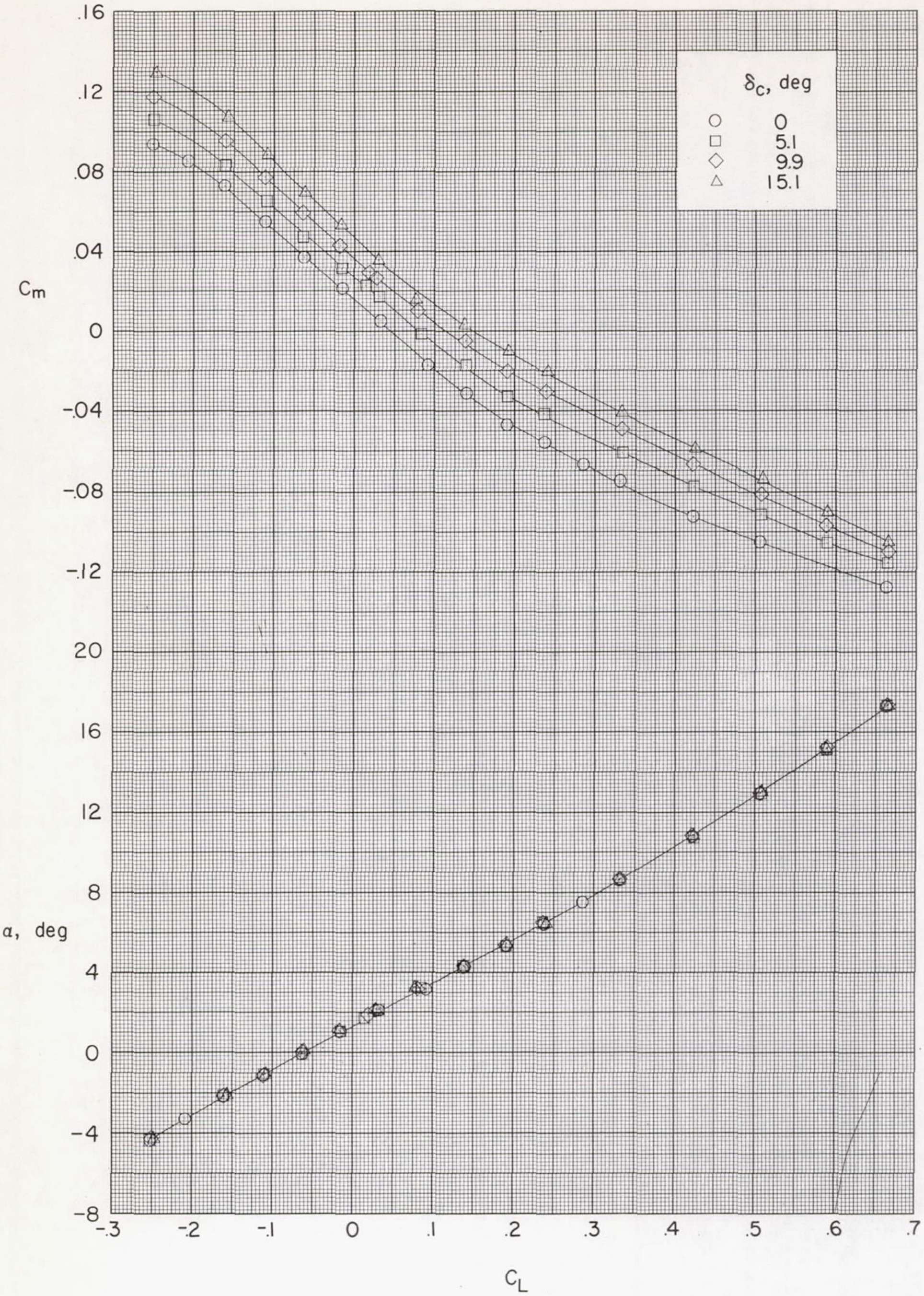
(a) Variation of C_m and α with C_L.

Figure 6.- Aerodynamic characteristics in pitch for various combinations of component parts. Plane wing; medium canard; $M = 2.01$; $\delta_c = 0^{\circ}$.



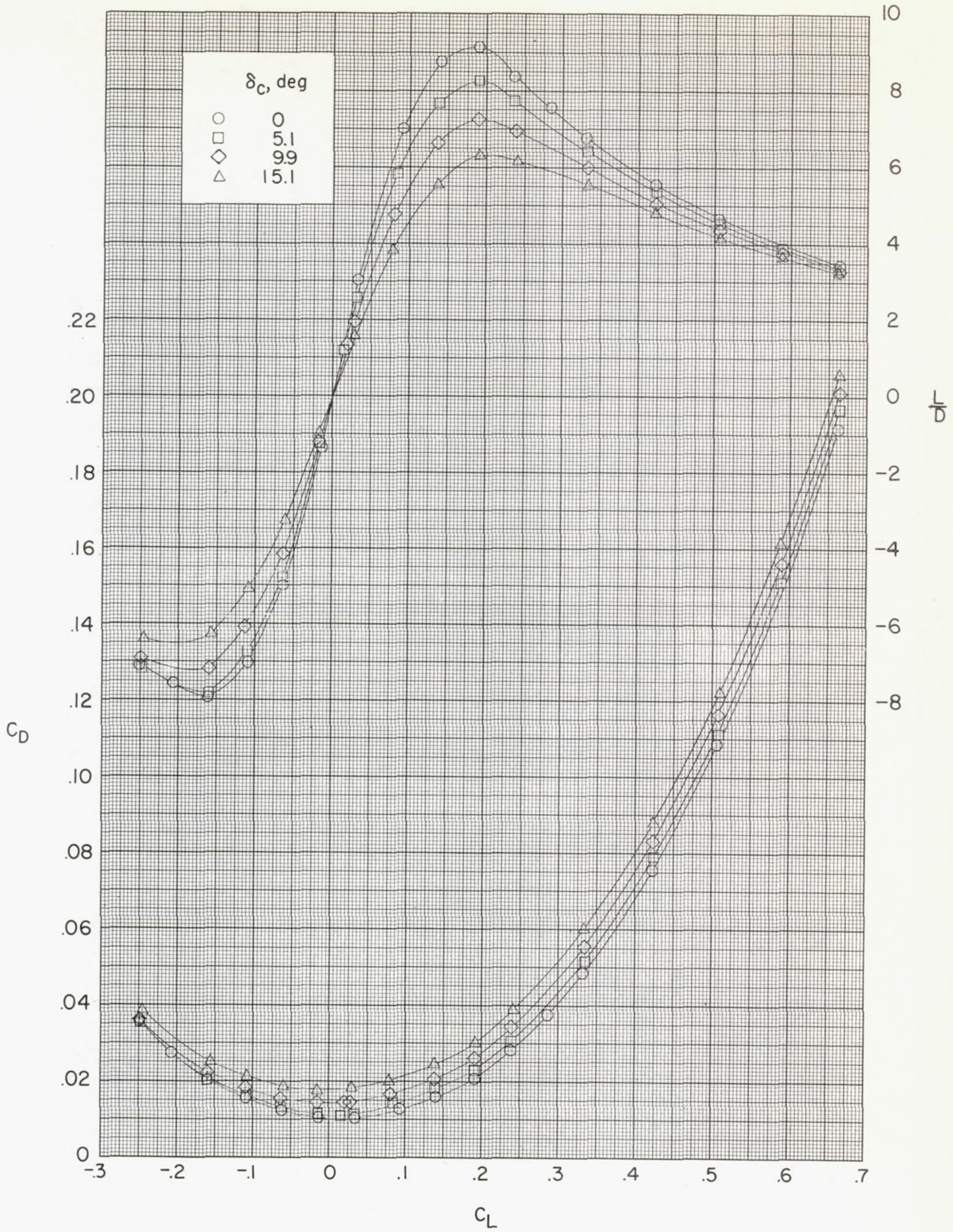
(b) Variation of L/D and C_D with C_L.

Figure 6.- Concluded.



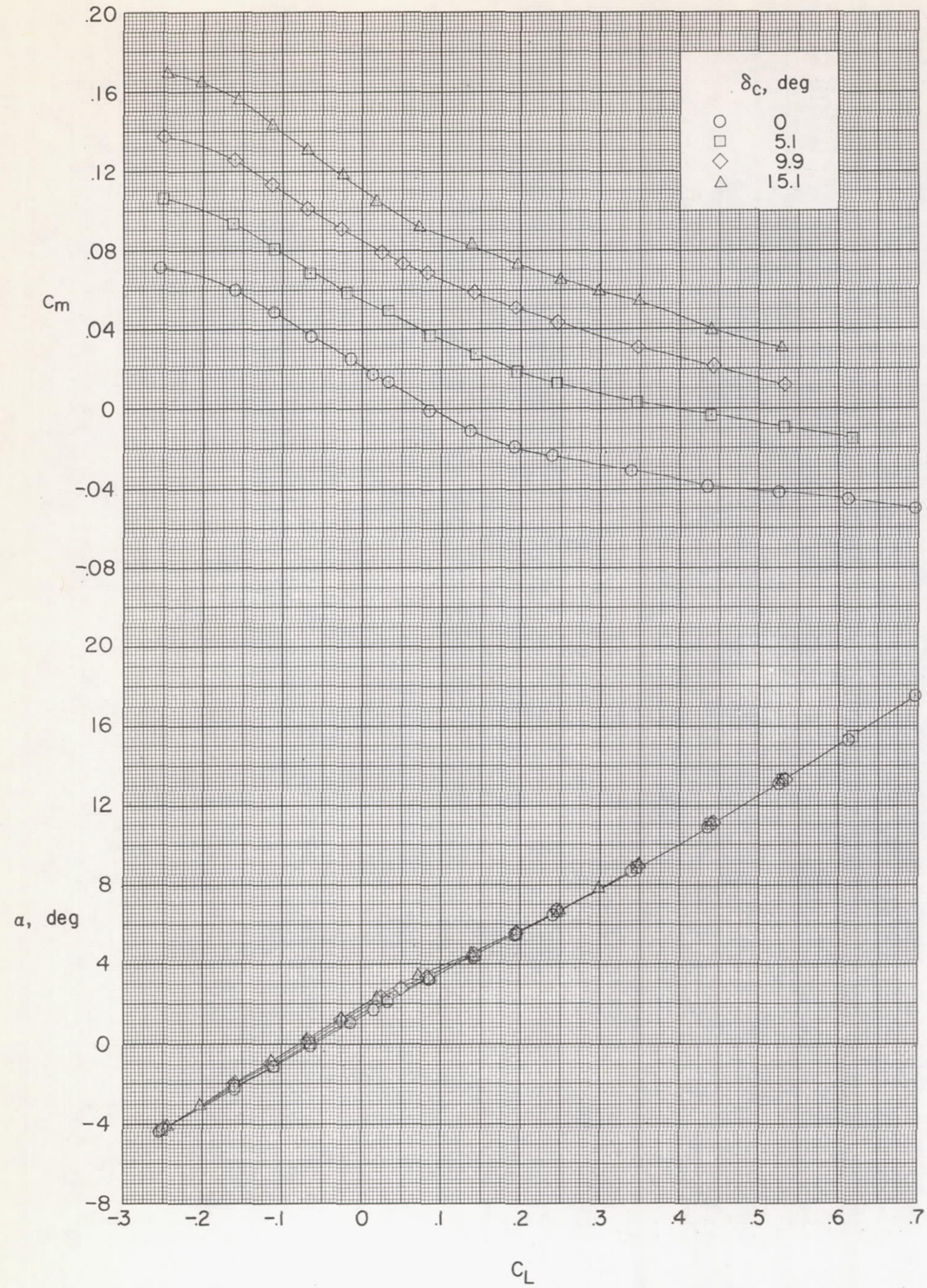
(a) Variation of C_m and α with C_L.

Figure 7.- Effect of control deflection on the aerodynamic characteristics in pitch. Small canard; twisted wing; vertical tail on; M = 1.41.



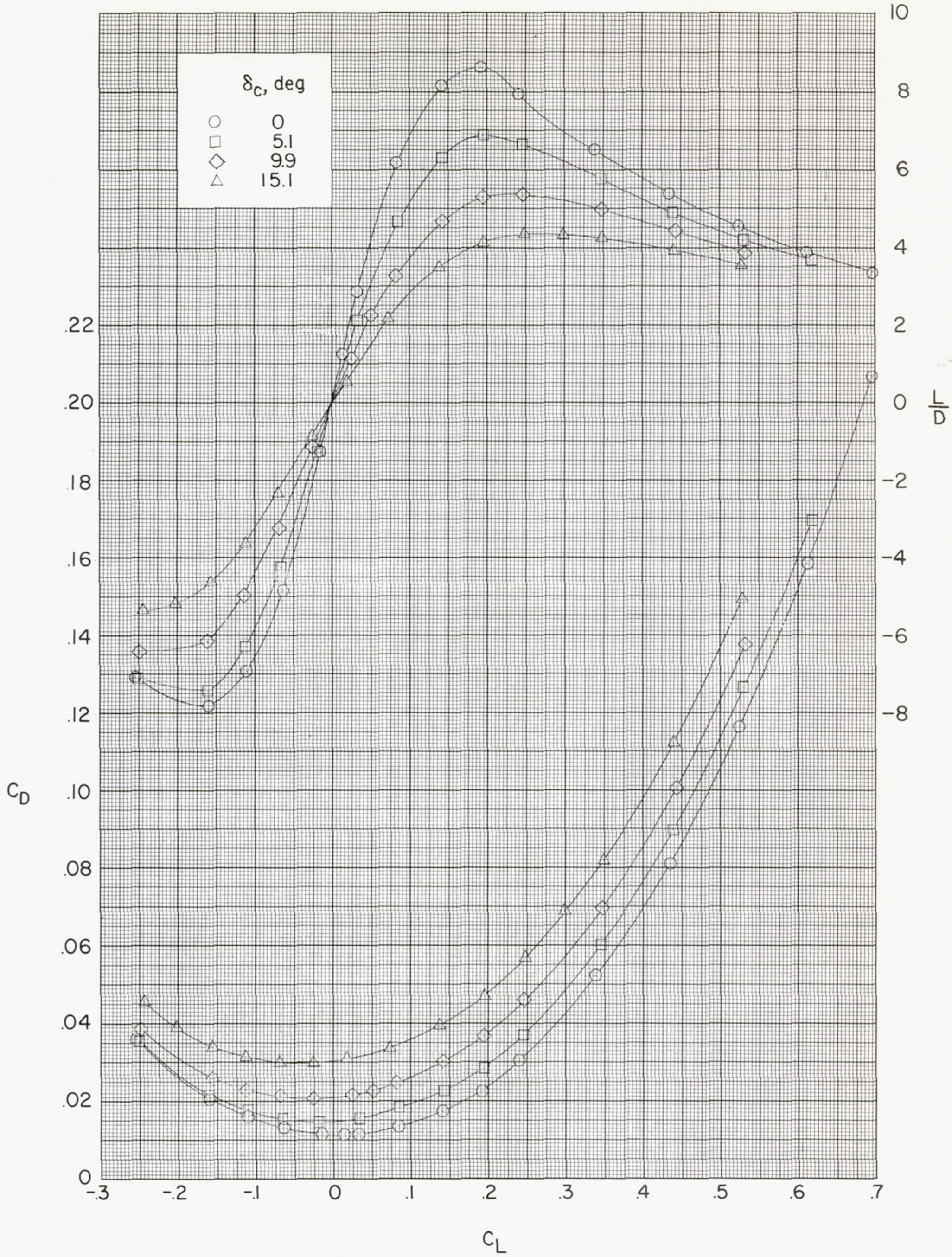
(b) Variation of L/D and C_D with C_L

Figure 7.- Concluded.



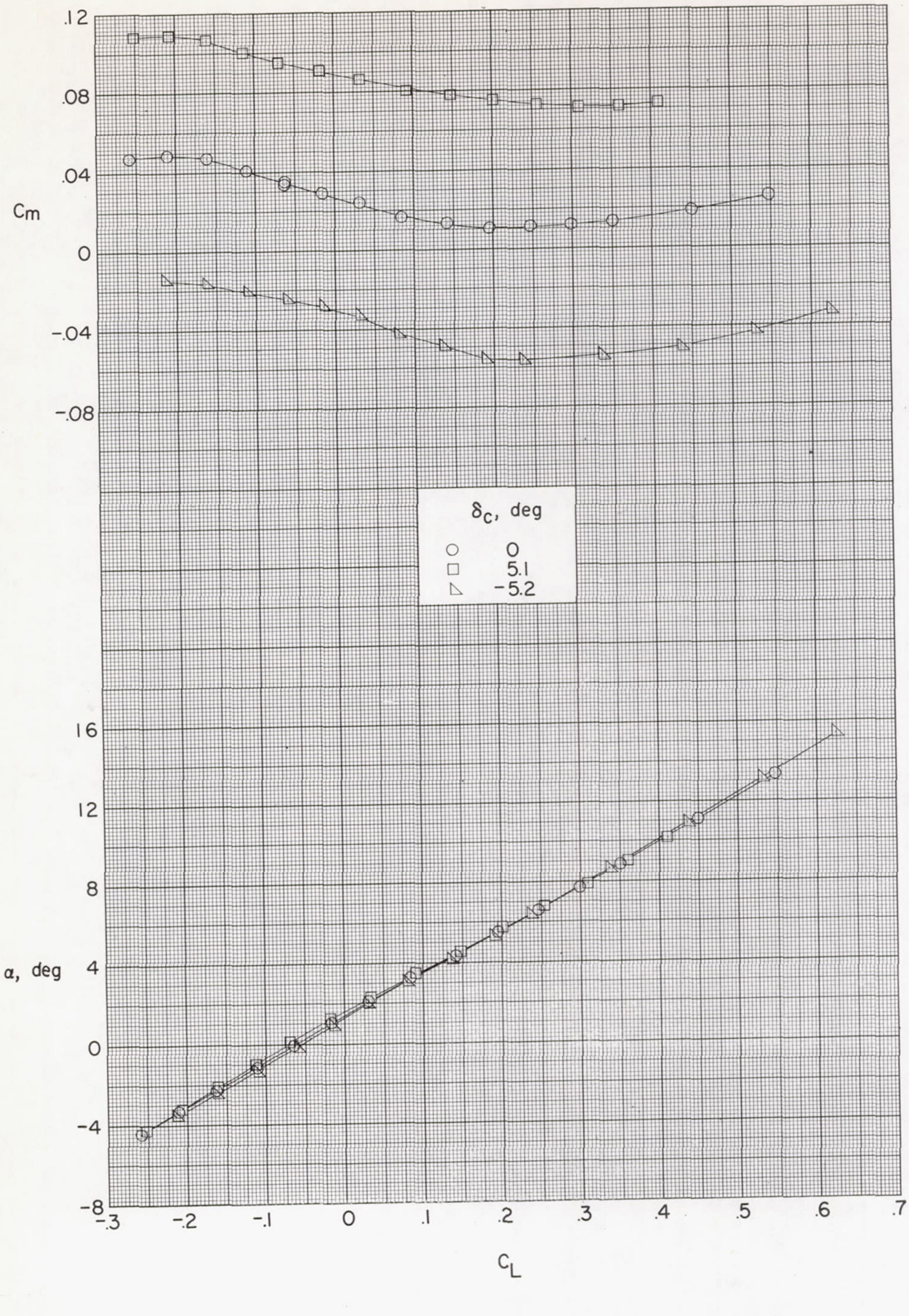
(a) Variation of C_m and α with C_L.

Figure 8.- Effect of control deflection on the aerodynamic characteristics in pitch. Medium canard; twisted wing; vertical tail on; M = 1.41.



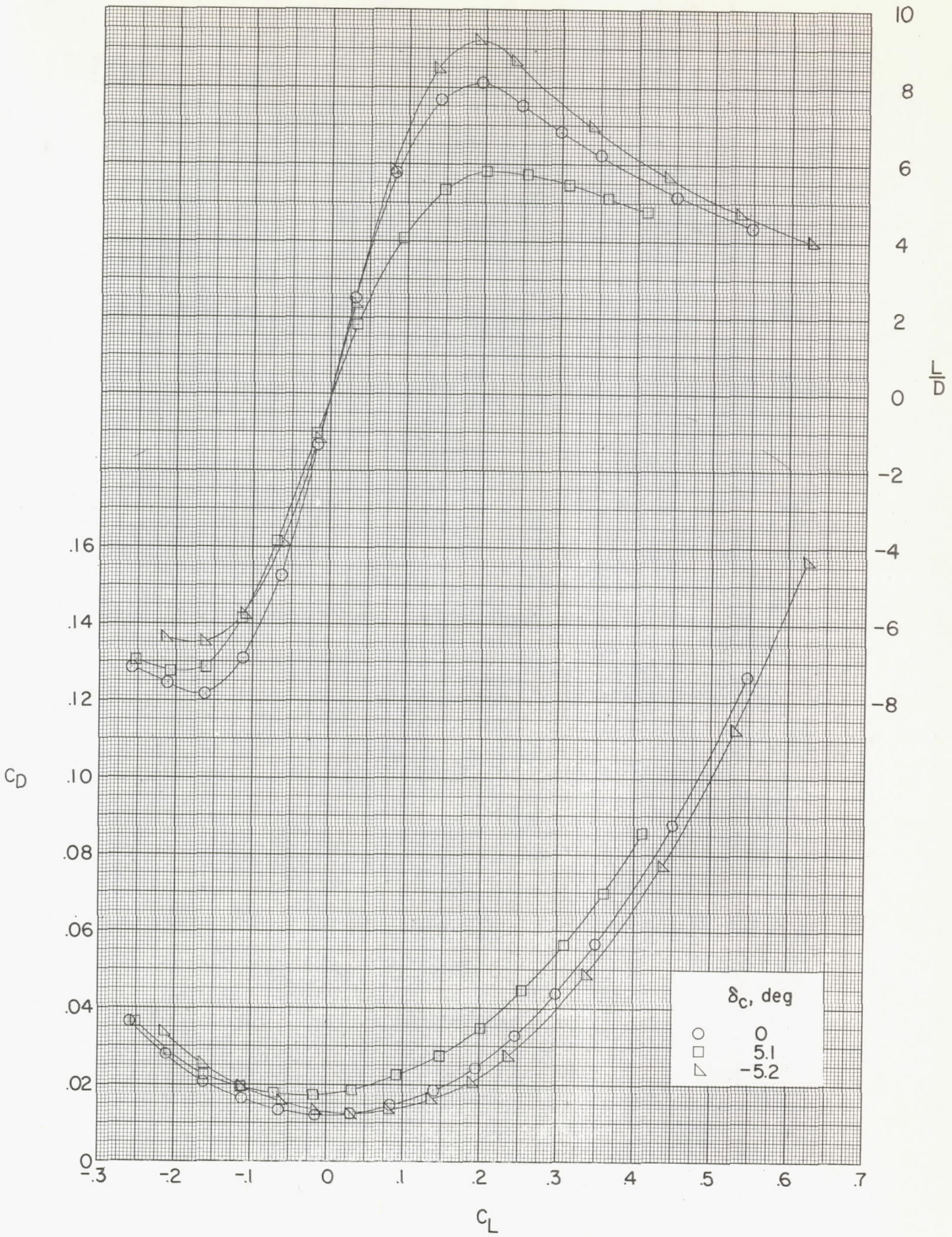
(b) Variation of L/D and C_D with C_L.

Figure 8.- Concluded.



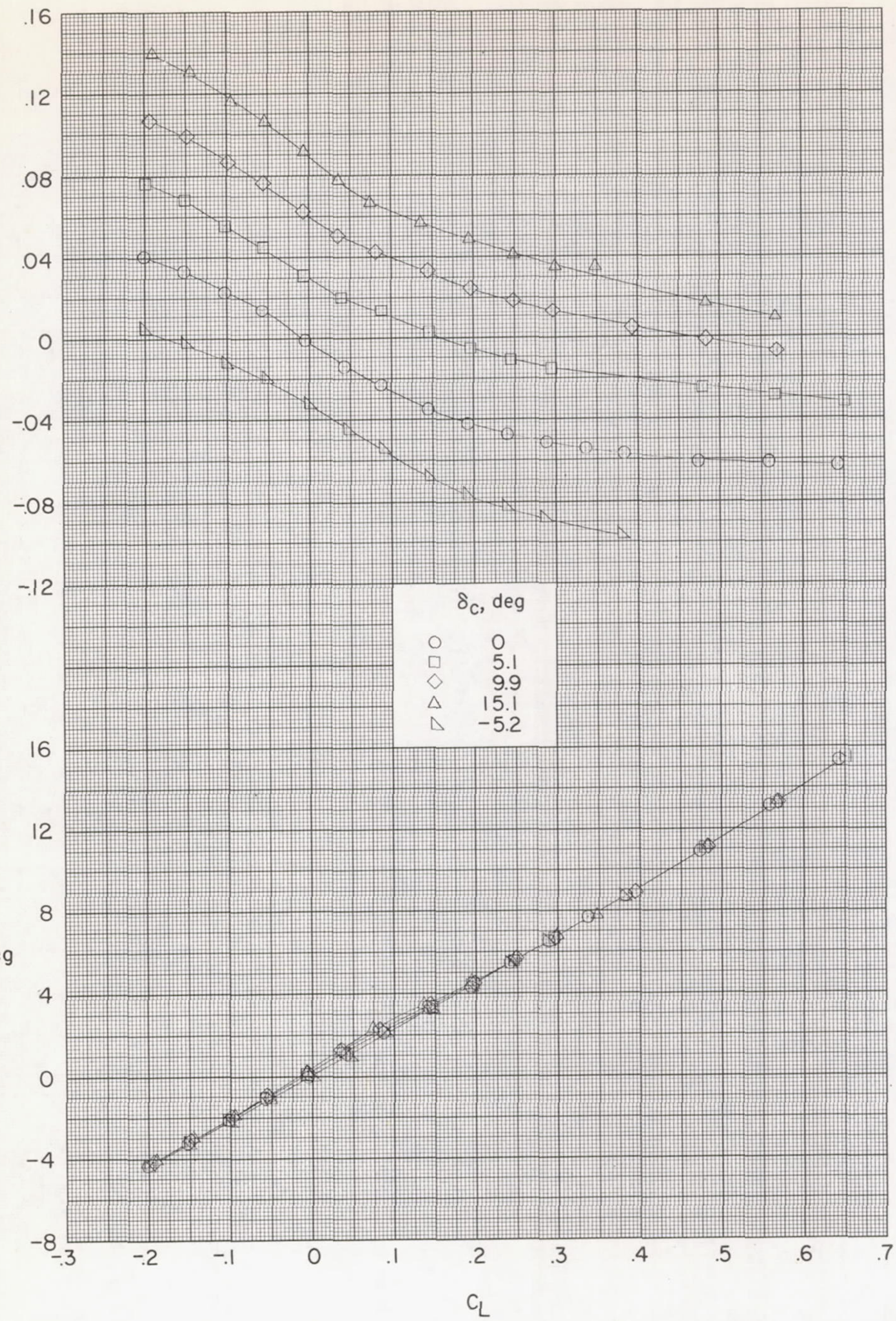
(a) Variation of C_m and α with C_L.

Figure 9.- Effect of control deflection on the aerodynamic characteristics in pitch. Large canard; twisted wing; vertical tail on; $M = 1.41$.



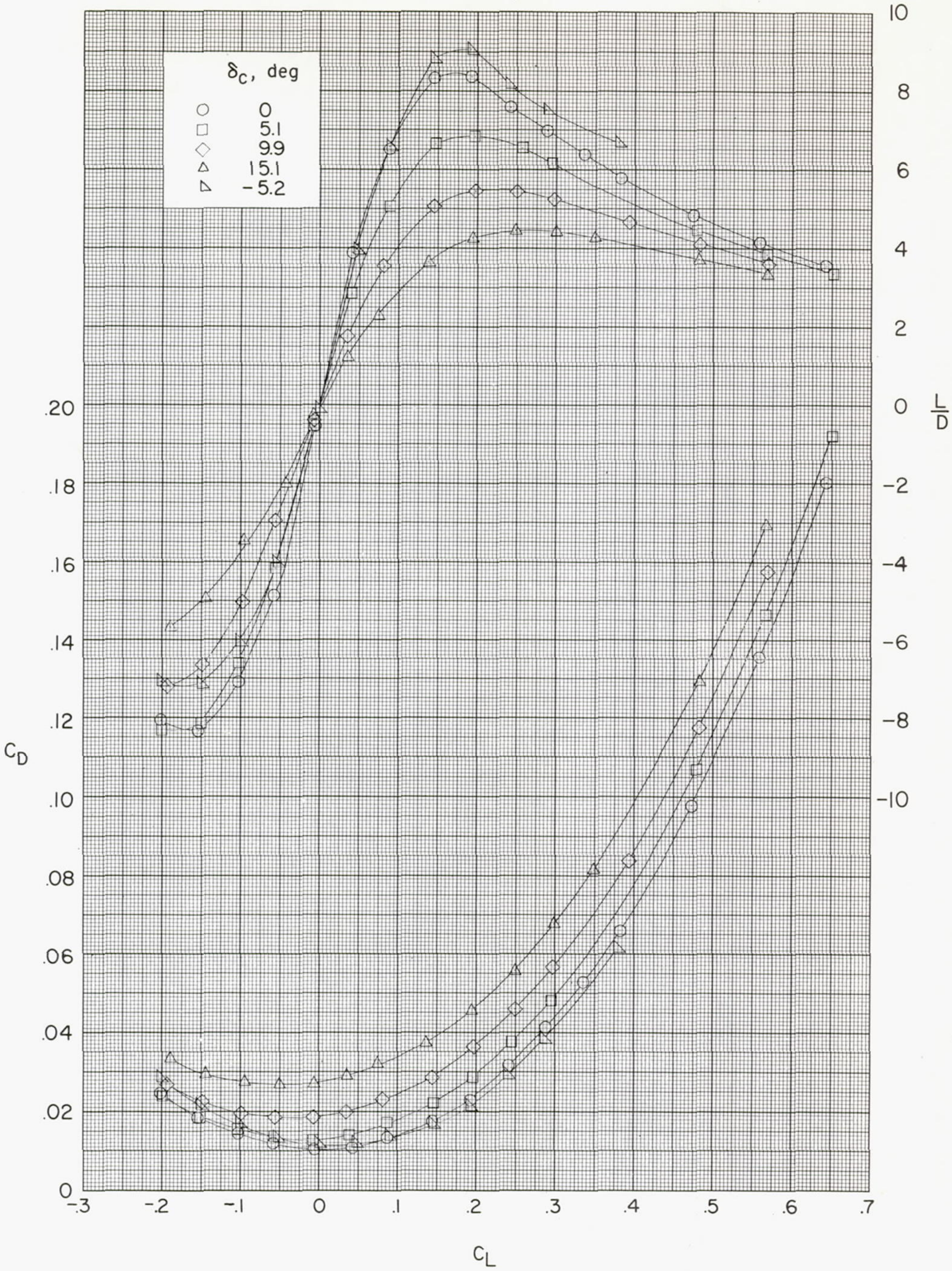
(b) Variation of L/D and C_D with C_L.

Figure 9.- Concluded.



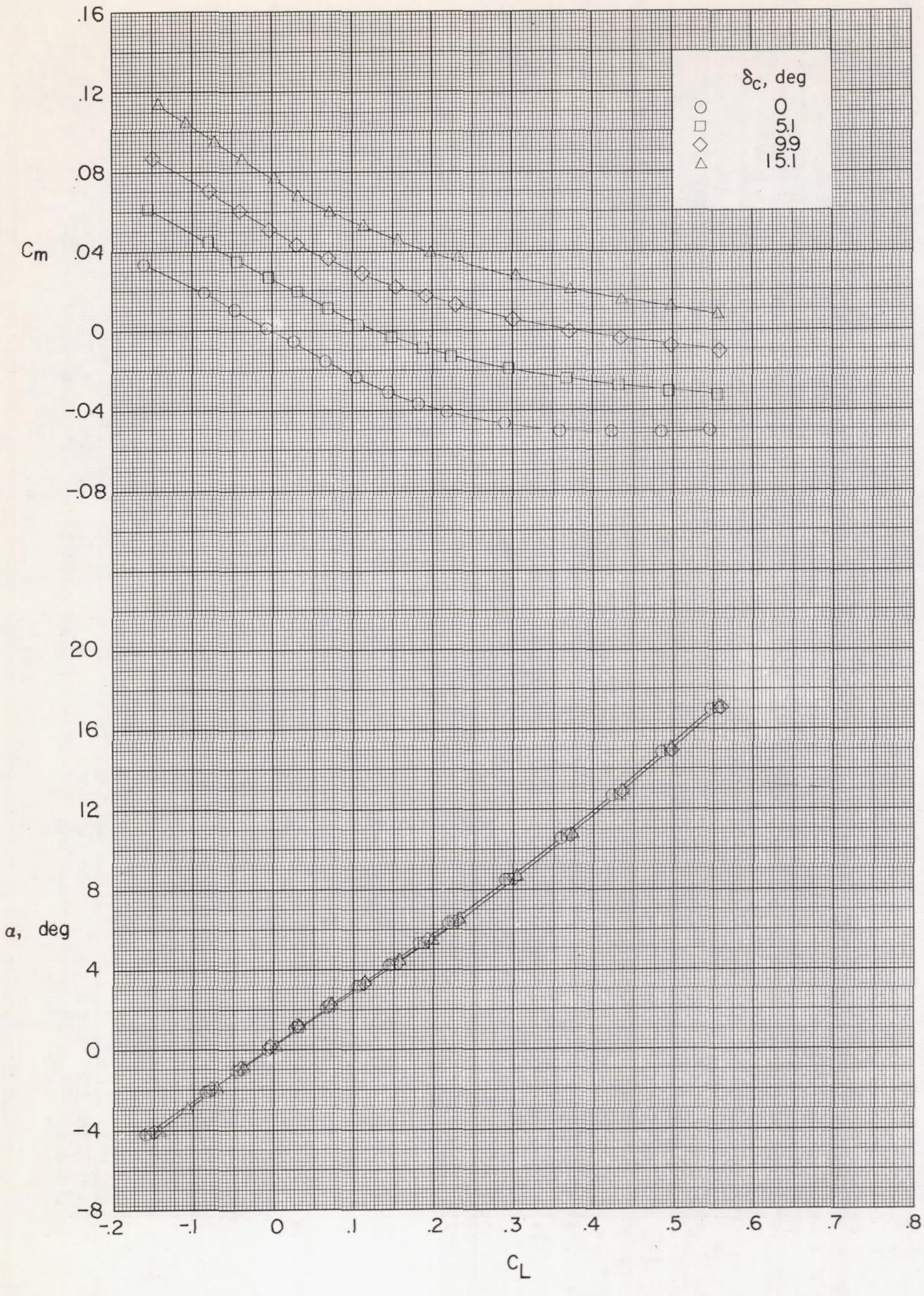
(a) Variation of C_m and α with C_L.

Figure 10.- Effect of control deflection on the aerodynamic characteristics in pitch. Medium canard; plane wing; vertical tail on; M = 1.41.



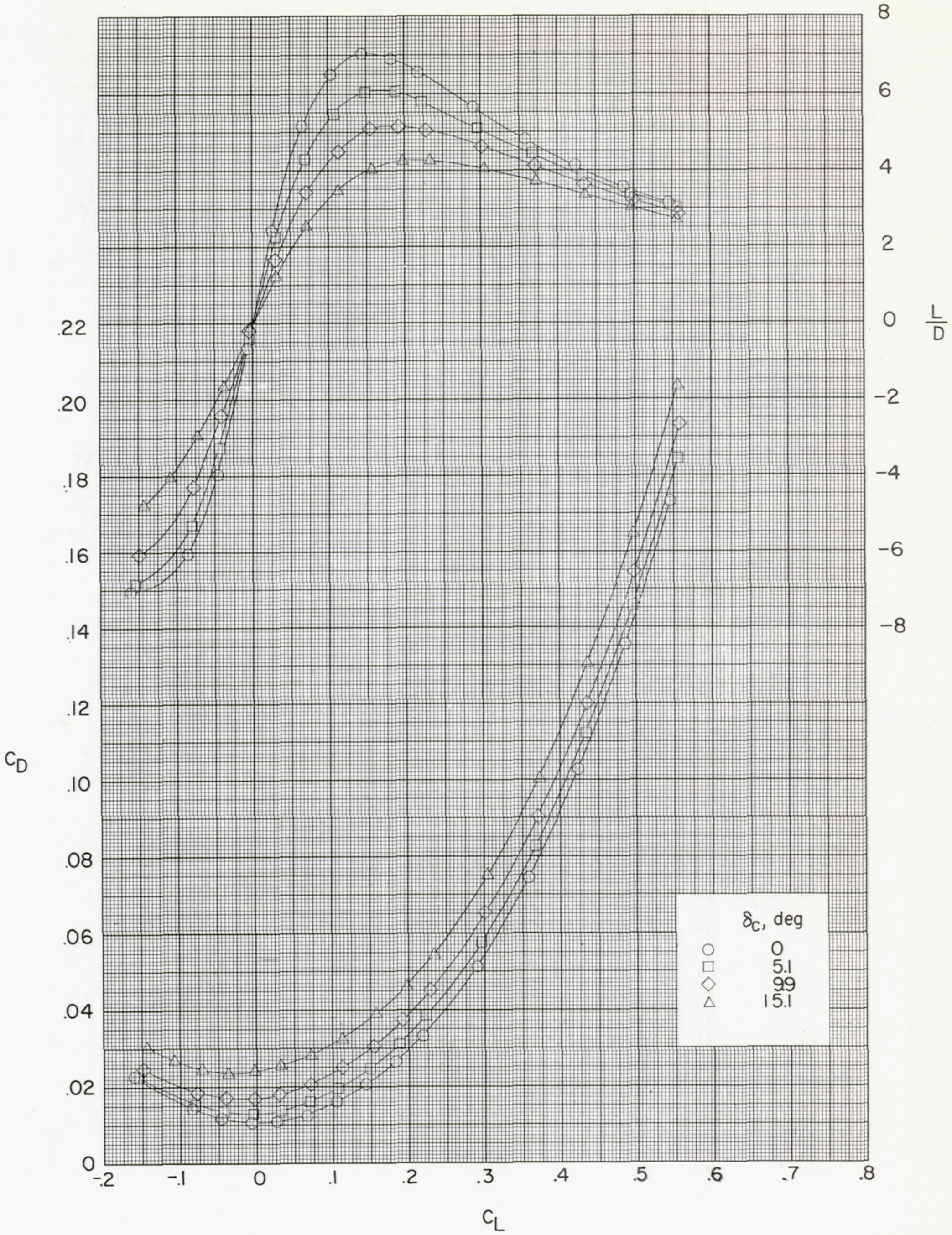
(b) Variation of L/D and C_D with C_L.

Figure 10.- Concluded.



(a) Variation of C_m and α with C_L.

Figure 11.- Effect of control deflection on the aerodynamic characteristics in pitch. Medium canard; plane wing; vertical tail on; M = 2.01.



(b) Variation of L/D and C_D with C_L.

Figure 11.- Concluded.

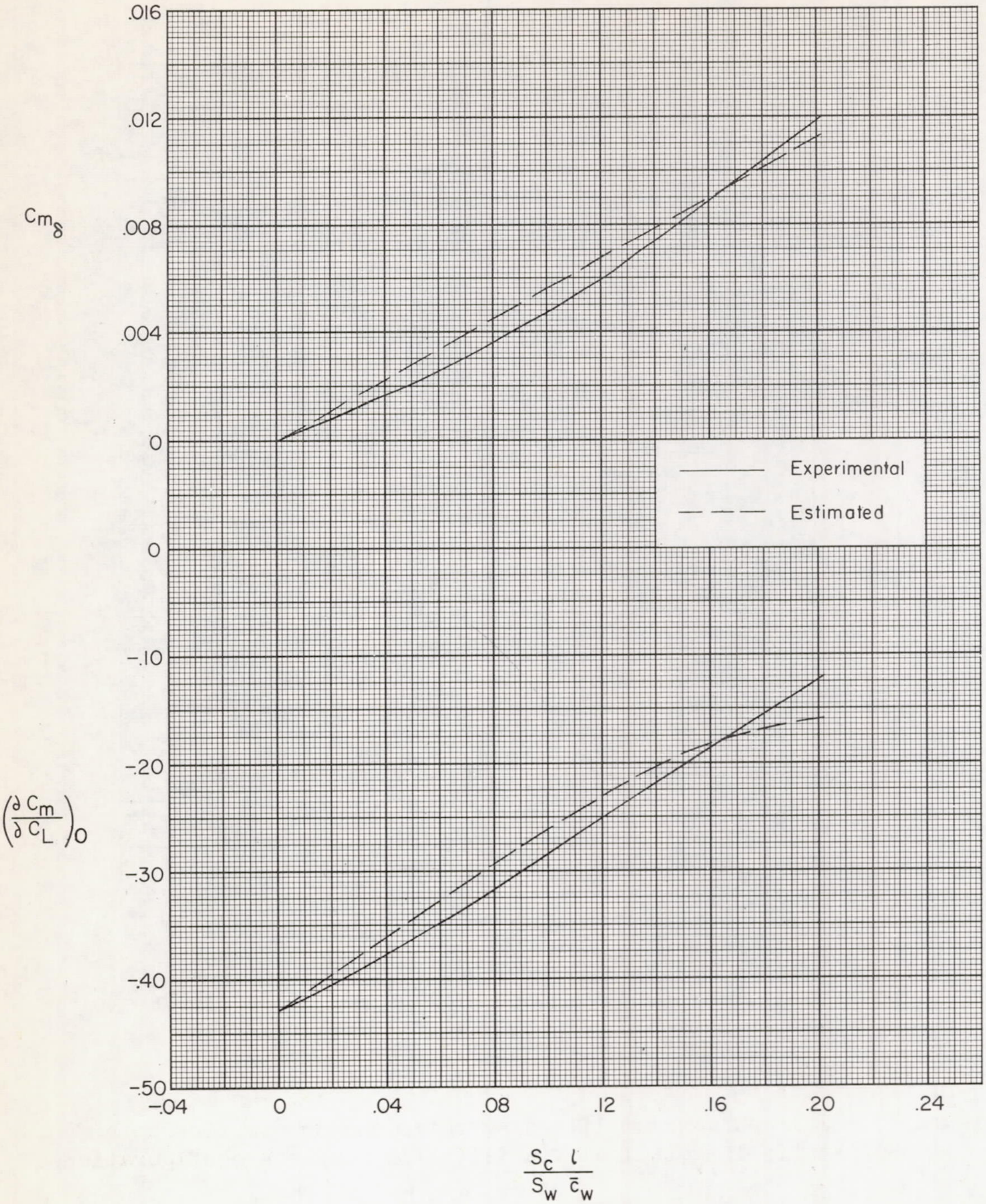


Figure 12.- Variation of control pitch effectiveness and static longitudinal stability with canard volume coefficient. Twisted wing; complete configuration; M = 1.41.

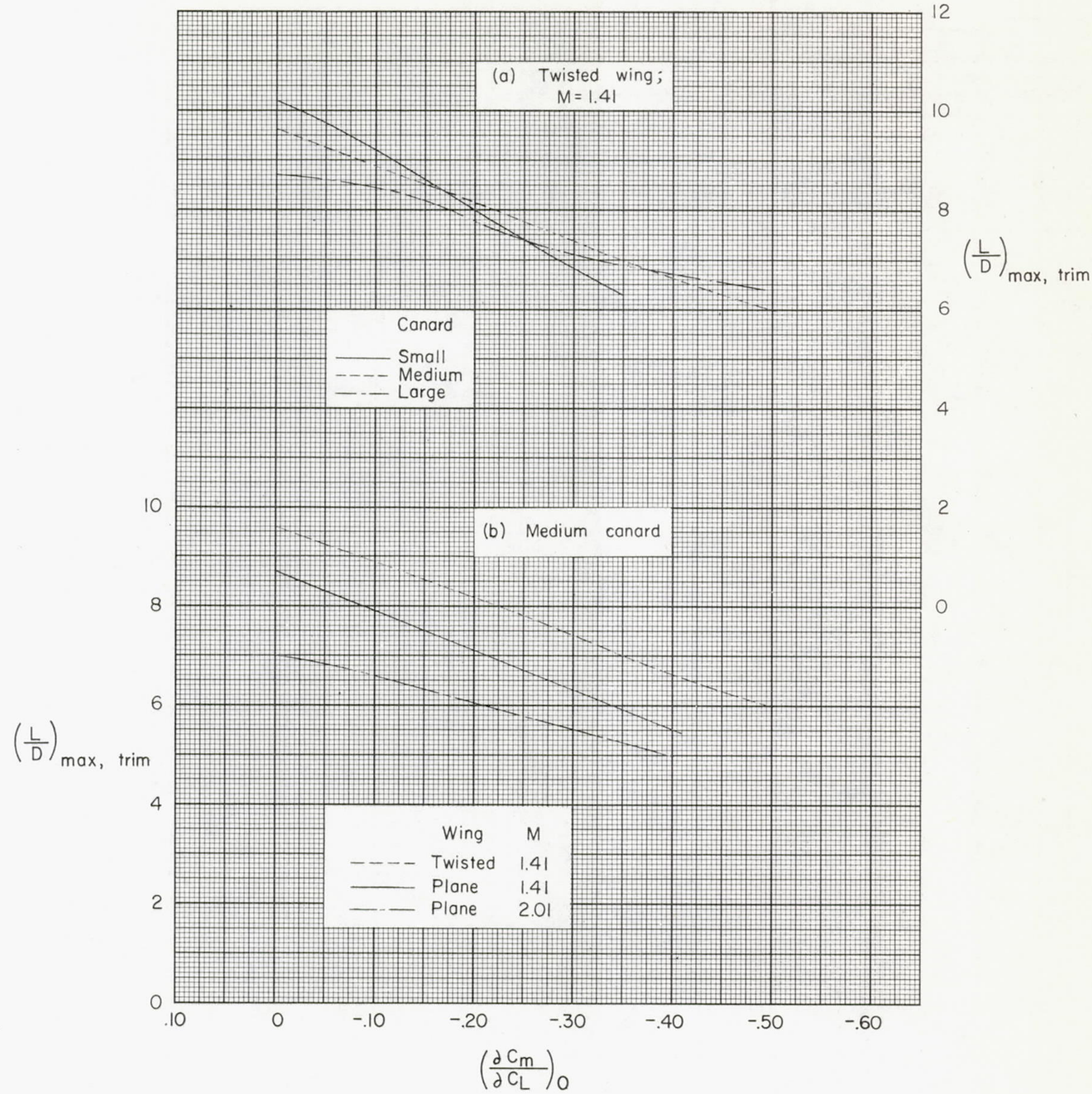


Figure 13.- Trimmed maximum lift-drag-ratio characteristics as a function of static longitudinal stability for complete configurations.